

1990 Windsor Workshop on Alternative Fuels

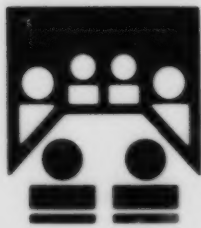
Sponsored by

Energy, Mines &
Resources Canada,
U.S. Department of Energy
and
Ontario Ministry of Energy

Presented by

ORTECH International

Holiday Inn
Toronto Downtown - City Hall
Toronto, Ontario
JUNE 11 - 14, 1990



PROCEEDINGS

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**PROCEEDINGS OF THE 1990 WINDSOR WORKSHOP
ON ALTERNATIVE FUELS**

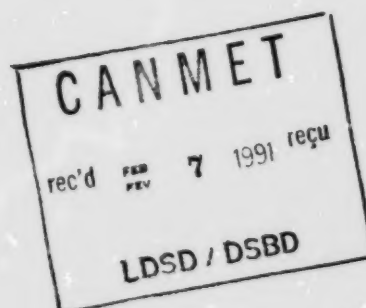
**JUNE 11 - 14, 1990
TORONTO, ONTARIO**

SPONSORED BY:

Energy, Mines and Resources Canada

United States Department of Energy

Ontario Ministry of Energy



October 1990

PREFACE

Energy, Mines and Resources Canada (CANMET) and the U.S. Department of Energy were pleased once again to host the Windsor Workshop on Alternative Fuels. We also welcome this year, the sponsorship of the Ontario Ministry of Energy.

Over 350 delegates, from at least 7 countries participated in this conference, making it one of the most important and perhaps the most unique avenue to exchange relevant information on the question of alternative fuels. Unique because the workshop brought together all alternative energy proponents with engine and vehicle manufacturers, fuel suppliers, research organizations in both the public and private sectors, academic and regulatory bodies in an informal setting. The workshop was not a meeting of the converted, rather, a forum for debate between opponents. This format proved to be quite successful, and we intend to continue holding the workshops in this fashion because they generate honest discussions between the participants.

When reading through these proceedings, you'll appreciate that, in keeping with the informal format, not all papers are in text form. Some are a compilation of slides presented by the speakers; we hope that the discussions and notes taken by each participant will complement the package. If not, we encourage you to contact the speakers and discuss the issues you may have with them. You will find a list of participants at the end of the proceedings.

We look forward to holding the next Alternative Fuels Workshop. We hope to see all of this year's delegates next year so that we may carry on our discussions and witness the progression of our ideas.

We wish to thank everyone for their commitment to the field of alternative fuels, the workshop organizers and all of those people who were involved in some form or another in the organization of this event.

Bernie James
Energy, Mines and
Resources Canada

Jerry Alisup
Department of Energy
United States of America

John Hutchison
Ontario Ministry
of Energy

1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 11 - 14, 1990

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**SESSION 1 - LIGHT/MEDIUM DUTY VEHICLES
A - NATURAL GAS**

Co-Chairs: R. Neville, ORTECH International
R. McGill, Oak Ridge National Laboratory

1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

**PROPANE FUELED ENGINES AND THE IMPACT
OF DECREASING TEMPERATURE ON EXHAUST
EMISSIONS - A YEAR ROUND ADVANTAGE**

BY

C. S. DEMPSEY

PROPANE GAS ASSOCIATION OF CANADA INC.

JUNE 11, 1990

CSD

**PROPANE FUELED ENGINES AND THE IMPACT
OF DECREASING TEMPERATURE ON EXHAUST
EMISSIONS - A YEAR ROUND ADVANTAGE**

1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

Under contract with the PGAC, a series of exhaust emission tests were carried by the Vehicle Emissions Testing Laboratory staff in their Ottawa Environmental Technology Centre test facilities over the period September 1989 to April 1990. The purpose was to develop Canadian data on gasoline spark ignition engined vehicles before and after conversion to propane fuel.

The test protocol used was the Canadian Motor Vehicle Safety Standards (MVSS), the Urban Dynamometer Test Schedule (UDDS) following the U.S. EPA Federal Test Procedure (FTP) which has been used for vehicle emission evaluation since the mid 1970's in North America. Normally the FTP is run at 21°C (70°F) and for baseline data this temperature regime for air temperature in the test cells was followed. Indolene (the standard fuel for gasoline engine exhaust emission measurement) was used for data base and comparative purposes.

Two vehicles were selected for reasons of general popularity for conversion to propane, a Chevrolet Silverado 5.7 litre V-8 and a Ford F-150 pick-up truck with a 5.0 litre V-8. The Chevrolet was a dual injector TBI (throttle body injection) gasoline fuel system. The Ford was an MFI (multi-point fuel injection) system.

The engine fuel systems were converted to propane fuel after run-in and data collection on gasoline (indolene). Earlier in 1989, six propane conversion systems were selected and exhaust emission and fuel consumption evaluations carried out in a baseline study. Following this series of tests two conversion equipment systems for each of the two vehicles were selected for optimization and further test work which included an additional emission component evaluation using the HWFCT (highway fuel consumption test) schedule to represent a non-urban highway cruise engine operating condition for emission measurement.

The most recent project has been a cold weather test series. Our interest was in emissions from a number of aspects:

1. Normal operation;
2. Cold start and warm-up;

3. Highway operation;
4. Other emission components such as CO₂ for which no standard exists; and
5. Provide basic data from which to evaluate improved fuel system technology for propane fuelled vehicles.

The initial baseline work was instructive and the follow-up optimization work showed that the gasoline fuel emission standards could be met and with a balancing process between fuel consumption and emissions very significant changes were possible which allowed under the highway driving cycle at normal 21°C (70°F) test temperature extremely low CO (carbon monoxide) values to be achieved with some results (within the limitations of the measuring instrumentation) reaching zero.

Test Equipment and Emissions Measurement Techniques

The vehicles were run on a chassis dynamometer system to simulate vehicles loadings encountered in on road vehicle operation.

A Horiba Electric Dynamometer was used for all test work which, with a combination of mechanical and electrical systems, has an inertia weight simulation capability range of 1,000 to 10,000 lbs. and road load horse power of 0 to 50.

Rotational speed of the rolls with a vehicle in operation is measured by a photo electric pulse counter which transmits data to a microprocessor controller where it is translated and displayed to the vehicle operator on video screen showing a speed versus time trace.

The vehicle may be operated over a mix of idle, acceleration/deceleration and steady state conditions a repeatable combination of which is called a driving cycle.

The test cells are not temperature controlled. For cold weather data generation, it is necessary to open them up to atmosphere and allow inside/outside temperature to equalize before vehicles, parked outside, are rolled into the test cell.

Vehicle Specifications and Dynamometer Settings

<u>Vehicle</u>	<u>1989 Ford F-150</u>	<u>1989 Chevrolet Silverado</u>
Curb Weight lbs.	4,078	5,600
Inertia Weight lbs.	4,500	5,250
Road Load HP	14.5	15.0
Displacement Litre	5.0	5.7
Fuel System	MPFI	TBI
Number of Injectors	8	2
Transmission	Automatic 4 Speed	Automatic 4 Speed
Emission Controls	EGR Air Injection 3 Way Catalyst Electronic Fuel Injection Electronic Spark Advance Closed Loop System Canister	EGR - 3 Way Catalyst Electronic Fuel Injection - Open Loop Canister

PGAC Optimization Project 1989

A study completed by PGAC and Environment Canada on a 1989, 5 litre Ford F-150 and a 1989, 5.7 litre Chevrolet Silverado resulted in the following exhaust emission data for two makes of propane carburetion systems.

PGAC Optimization Project

CMVSS - UDDS Average Composite Exhaust Emission Rates

Grams/Mile

	Chevrolet				Ford		
	Std.	Indolene	A*	B*	Indolene	A*	B*
HC	0.8	0.41	0.33	0.42	0.75	1.31	1.01
CO	10	3.57	4.61	4.35	1.90	1.12	0.15
NOx	1.7	0.37	0.75	1.78	1.30	0.84	1.47
CO ₂	-	611.17	527.65	511.77	545.10	492.80	478.48

CMVSS - HWFCT Average Composite Exhaust Emission Rates

Carburetion System	Chevrolet			Ford		
	Indolene	A*	B*	Indolene	A*	B*
HC	0.09	0.08	0.04	0.15	0.55	0.43
CO	1.04	0.72	0.00	0.52	0.49	0.02
NOx	0.13	0.20	2.03	1.14	0.85	1.45
CO ₂	455.77	381.28	365.67	443.60	386.00	347.77

CMVSS - Canadian Motor Vehicle Safety Standard

UDDS - Urban Dynamometer Driving Schedule

HWCFT - Highway Fuel Consumption Test

* Propane Conversion System

Note: Unburned hydrocarbon exhaust emissions from propane fuelled vehicles are less reactive than those emitted by gasoline fuelled vehicles.

Having achieved improvements over the baseline and determined that by balancing the fuel emissions and fuel consumption all the standard maximum levels for HCs, CO and NOx could readily be met we moved into a lower temperature regime.

Low Ambient Temperature Emission Results

The range for the lower temperature emission measurement was 11°C to -5°C and at this level VETL obtained some very significant results which are best illustrated graphically by a series of best fit lines for a number of test values for indolene and propane obtained from a series of test runs for each fuel type in addition to the numerical data.

I will start with HCs and then move onto CO, NOx and CO₂ and as can be seen for both vehicles there is considerable difference for the full test mean values on the UDD Schedule between gasoline and propane at cool and cold ambient temperatures.

Urban Dynamometer Driving Schedule

Test Series Average Composite Results

Standard	0.8	10	1.7	No S ^d .
(g/mi)				

Ford F-150

	HC	CO	NOx	CO ₂	°C Ambient Start-Up Temperature
Indolene	1.62	16.80	1.12	579	7.5 (Average of 6 Runs)
Propane	1.20	0.04	0.80	555	3.9 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	74	.23	71	95	

Note: Propane test run average ambient temperature 5.2°C lower for the series.

Chevrolet Silverado

	HC	CO	NOx	CO ₂	Ambient Start-Up Temperature °C
Indolene	0.67	10.90	1.10	591	7.7 (Average of 6 Runs)
Propane	0.30	4.67	0.36	561	9.3 (Average of 6 Runs)
Propane Emissions as a Percent of Indolene	44	43	31	95	

The UDD schedule is normally carried out at 21°C (70°F). The results show the major difference between vehicles run on gasoline (indolene) and propane at lower temperatures which more closely approximate Canadian ambient temperatures for much of the year.

Cold Start (UDDS First Bag Results)

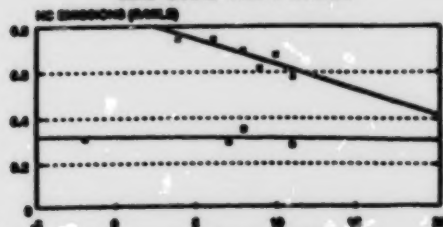
First 505 seconds of the 505 S, 875 S, 505 S test schedule time sequence start from cold (first bag results).

If the first 505 seconds (8.4 minutes) of engine operation after start-up from cold emissions are compared the advantage of propane over gasoline is vividly illustrated.

	HC	CO	NOx	CO ₂	Ambient Start-Up °C Temperature
Ford F-150					
Indolene	5.77	78.94	1.78	503	8.1 (Average of 6 Runs)
Propane	1.58	0.28	1.46	595	3.2 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	27	0.35	82	118	

COLD WEATHER RESULTS

GM 5.7L TBI PICKUP



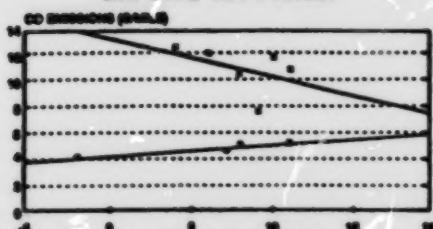
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



GM 5.7L TBI PICKUP



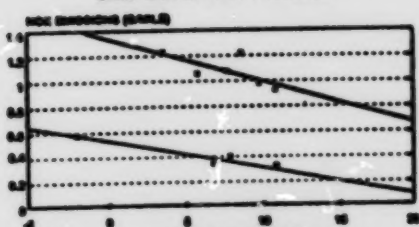
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



GM 5.7L TBI PICKUP



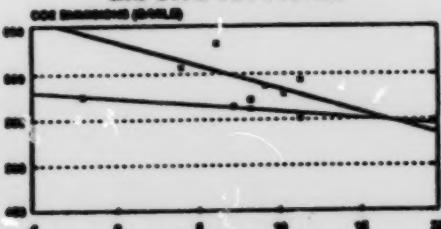
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



GM 5.7L TBI PICKUP



US04 DRIVING CYCLE

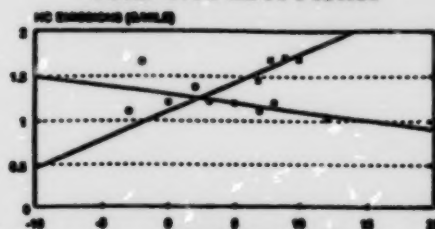
TEMPERATURE (DEG C)

• PROPANE • GASOLINE



COLD WEATHER RESULTS

FORD 5.0L MPFI PICKUP



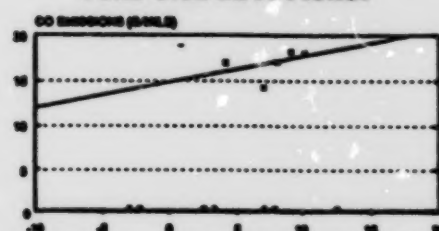
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



FORD 5.0L MPFI PICKUP



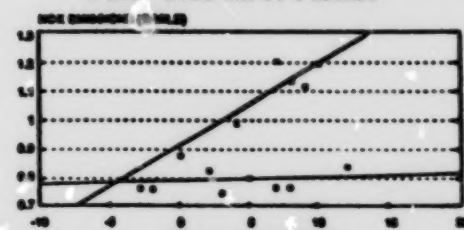
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



FORD 5.0L MPFI PICKUP



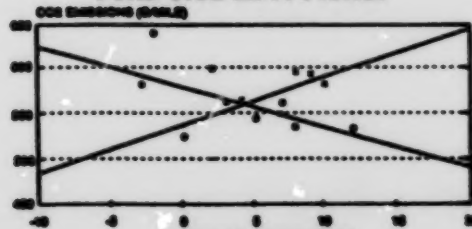
US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



FORD 5.0L MPFI PICKUP



US04 DRIVING CYCLE

TEMPERATURE (DEG C)

• PROPANE • GASOLINE



	HC	CO	NOx	CO ₂	Ambient Start-Up Temperature °C
Chevrolet Silverado					
Indolene	2.77	51.9	1.70	582	7 (Average of 6 Runs)
Propane	1.09	20.82	0.80	557	7.8 (Average of 14 Runs)
Propane Emissions as a Percent of Indolene	39	40	46	96	

When one considers how many times vehicles are started and run for only 8 to 10 minutes this part of a driving cycle pattern is a very big contributor to the inventory of exhaust emissions, and any reductions at this stage make a disproportionately large contribution to improving air quality.

In our large cities particularly, and elsewhere to a less concentrated degree, when the normal work day starts, which can be once or seven times a week, millions of vehicles are individually evolving a high concentration of emissions and collectively contributing high levels over a short time period, two to three hours in the morning then a repeat of the exercise at the end of the day for a similar period of time.

We think there will be general agreement that to make a significant contribution is important and propane as an alternative fuel certainly has not approached its potential but is already a very attractive environmental option.

Conclusions

- o At normal temperature, propane fuelled engines can meet the gasoline exhaust emissions standards and with fine tuning, show improvement in emissions compared to the same vehicles run on indolene.
- o Under highway driving conditions, propane CO levels are significantly below those for indolene.
- o At cool/cold start conditions propane shows a significant improvement over indolene (gasoline) fuelled engines.

Acknowledgments

I would like to acknowledge the contribution of the Propane Gas Association of Canada Inc. members in supporting this work, the Canadian Auto Propane Council. The Federal Department of Energy, Mines and Resources and Ontario Ministry of Energy in co-sponsoring the work and the Vehicle Emissions Testing Laboratory of Environment Canada, the staff of which were extremely cooperative and enthusiastic in conducting the test work and answering all of my questions. General Motors of Canada for providing a vehicle for tests and being extremely patient with our efforts to hit the right weather conditions.

WINDSOR

**CNG FUEL SYSTEM
DEVELOPMENT FOR 427 CID ENGINE**

**1990 WINDSOR WORKSHOP ON
ALTERNATIVE FUELS
TORONTO, ONTARIO**

JUNE 11, 1990

PRESENTATION OUTLINE

- I. Program Description**
- II. Engine Development**
- III. Engine Control System**
- IV. CNG Fuel Injector Development**

PROGRAM OBJECTIVES

- Develop Natural Gas Engine and Fuel System for Route Vehicle Fleet Operation
 - Meet 1994 Truck Emission Standards
 - Best Performance
 - Low Cost Premiums
 - No Maintenance/Durability Penalties

TECHNICAL APPROACH

ENGINE

- Modify GM 427 Gasoline Engine for CNG

CONTROLS

- Modify Delco Electronics Gasoline Controller

FUEL INJECTORS

- Develop Gaseous Fuel Injectors

ENGINE DEVELOPMENT

- **Modify General Motors 427 CID (7.0 Liter) Gasoline Engine for CNG**
- **TecoDrive 7000 Engine (7.0 Liter)**
 - Tecogen Gas Engine Technology
 - High Compression Pistons
 - Match 6.0 Litre Gasoline Performance

VEHICLE OEM PRODUCTION BASED CONTROLS

- Work with Controls OEM Delco Electronics
- Use Automotive Production Technology
 - Production Hardware
 - Production Software
 - Minimize CNG Related Changes
 - Stays Current

LOW COST CONTROLS AND CNG VEHICLES

- Uses Automotive Production Technology
 - Development Cost Already Sunk
 - Production Cost Already Sunk
 - Low Per Unit Cost
- Most Viable Approach to OEM CNG Vehicle Production
 - Minimum Production Cost
 - .. Few Changes
 - .. Volume Production Compatible
 - .. No Retrofit Costs
 - Full OEM Responsibility

STATE-OF-THE-ART CONTROLS

- Stoichiometric Air/Fuel Ratio
- Catalytic Exhaust Aftertreatment
- Closed Loop A/F Ratio Control
- Programmed Spark Advance
- Programmed EGR
- Optimized Performance
- Commercial Level Driveability
- Lowest Emissions

ECM OPERATING MODES

- Starting
- Idle Control
- Open Loop Running
- Closed Loop Running
- Acceleration/Deceleration
- Fuel Cutoff
- Block Learn

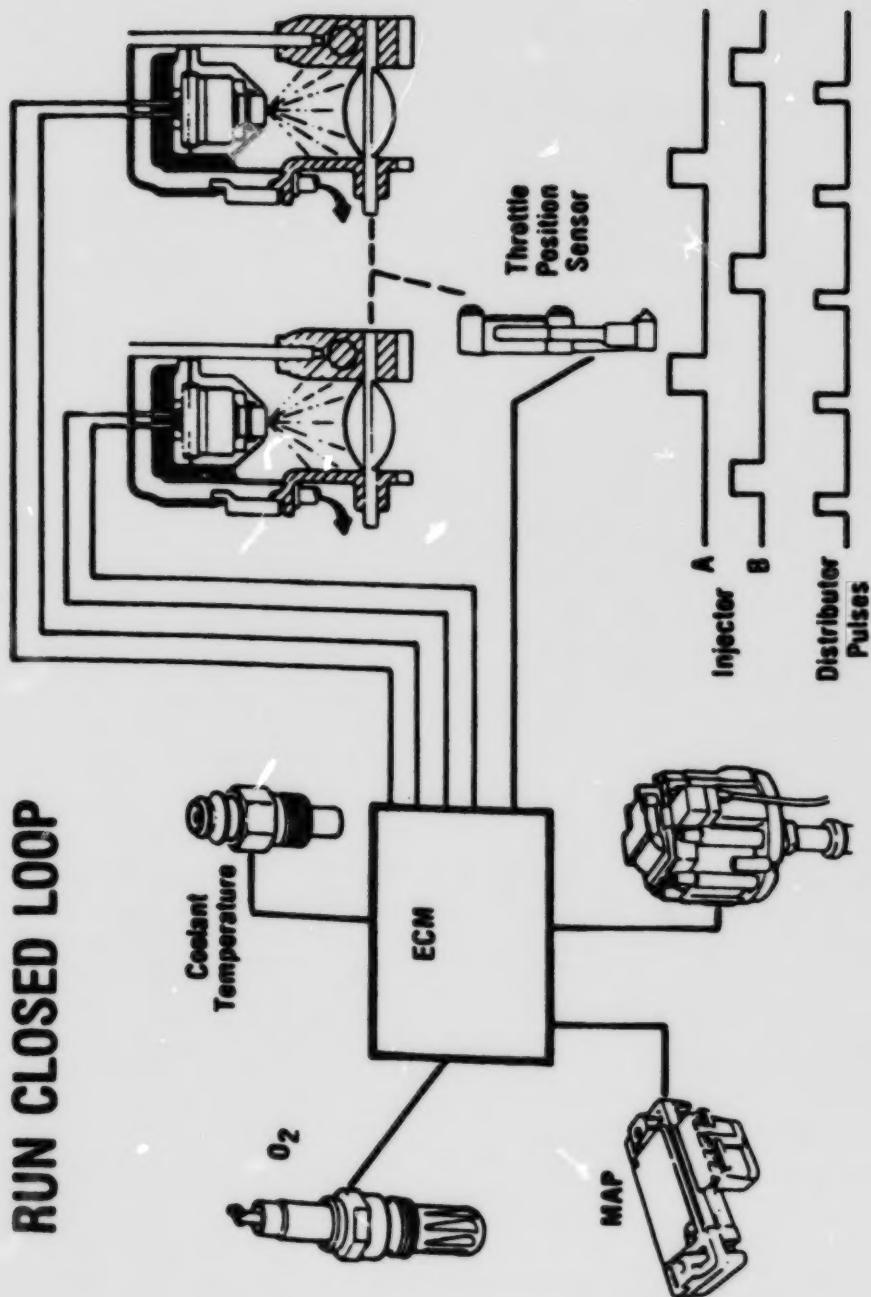
CONTROLLED ENGINE VARIABLES

- Idle Speed
- Spark Timing
- EGR Flow Rate
- Air Fuel Ratio
- Governed Engine Speed

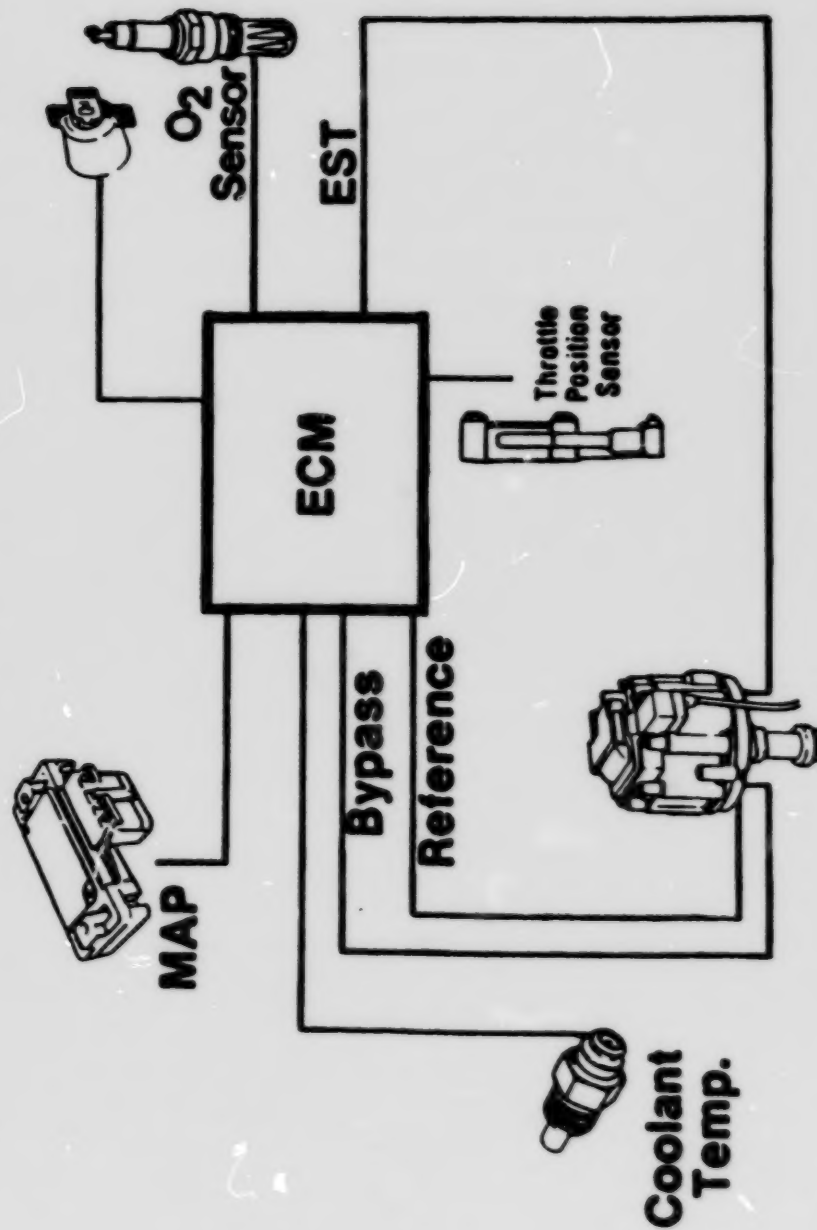
The diagram illustrates the components and airflow of a Throttle Body Injection (TBI) system. Key parts include:

- AIR FILTER**: Filters incoming air.
- CLEAN AIR**: The filtered air entering the system.
- TBI INJECTOR**: Sprays fuel into the air stream.
- THROTTLE BODY**: The main chamber where air and fuel mix.
- THROTTLE PLATE**: Controls the amount of air entering the throttle body.
- AIR BYPASS ORIFICE**: Allows air to bypass the throttle plate.
- AIR BYPASS PINTLE**: A valve that controls the bypass air flow.
- AIR BYPASS SEAT**: The seat for the bypass pintle.
- AIR BYPASS ACTUATOR/STEPPER MOTOR**: Controls the bypass pintle.
- ECM (Engine Control Module)**: The central control unit.
- IAC STEPPER MOTOR CONTROL LINES**: Connect the ECM to the IAC valve.
- Sensors**: Provide input to the ECM: BATTERY, IGNITION, ENGINE RPM, MAP, BARO, COOLANT, THROTTLE POS., PARK/NEUT SW, VEHICLE SPD, and A/C CLUTCH.

RUN CLOSED LOOP



Electronic Spark Timing



ENGINE CONTROL SYSTEM

SOFTWARE STRATEGY AND STATUS

- Closed Loop Stoichiometric A/F Ratio Control - Implemented and Functional
- Closed Loop Idle Speed Control - Implemented and Functional
- Open Loop Crank Mode - Implemented and Functional
- Closed Loop Engine Knock Control - Not Implemented
- Open Loop AE/DE - Implemented and Functional
Utility Not Verified
- Electronic Governor Control - Implemented and Functional

ELECTRONIC FUEL INJECTORS

- Dual Throttle Body Type
- Pulse Width Modulated
- Prototype Hardware

FUEL INJECTOR DEVELOPMENT STATUS

- First "Proof of Concept" Prototype Delivered
 - Adequate Flow Rate
 - Good Linearity
 - Reasonable But Somewhat Low Dynamic Range
 - Limited Durability
- Second Prototype Delivered
 - Higher Flow
 - Lower Operating Pressures

VEHICLE SYSTEM TESTING

- **TecoDrive 7000 Installed in Truck**
- **Fuel Injectors Installed on Engine**
- **PCM 6 ECM and Development System Installed in Truck**
- **Fuel Delivery System Designed and Installed**

VEHICLE SYSTEM TESTING RESULTS

- Fuel System
 - Good Driveability
 - Durability
- Control System
 - Appears to be Functioning Extremely Well
Given Preliminary Status of Calibration
- Engine
 - No Problems to Date
- Exhaust Emissions
 - Untested to Date
 - Requires ECM Vehicle Calibration

NATURAL GAS HEAVY-DUTY VEHICLE DEVELOPMENT (4.3L GM ENGINE)

1990 Windsor Workshop on Alternative Fuels

Presented by: Rebecca J. Royer

June 11, 1990

Acurex Corporation



PROJECT SPONSORS

Gas Research Institute

**New York State Energy Research and Development
Authority**

South Coast Air Quality Management District

California Energy Commission

Southern California Gas

Brooklyn Union Gas

United Parcel Service

General Motors Corporation

Union City Body Company

 **ACUREX
Corporation**

PROJECT OBJECTIVE

- **Develop a commercially feasible compressed natural gas vehicle for UPS delivery service**
 - **Low emissions**
 - **Attractive performance**
 - **Durability in fleet service**



ENGINE CONFIGURATION

FINAL CONFIGURATION

- Develop an optimized 4.3L natural gas engine
 - Lean-burn port fuel injection
 - Turbocharged
 - Increased Compression Ratio



ENGINE CONFIGURATION (concl.)

INTERIM CONFIGURATION

- Evaluate commercially available closed-loop natural gas technology
 - Emission control system changes
 - Engine calibration changes
- Emission and performance results to be compared with lean-burn configuration (currently under development)

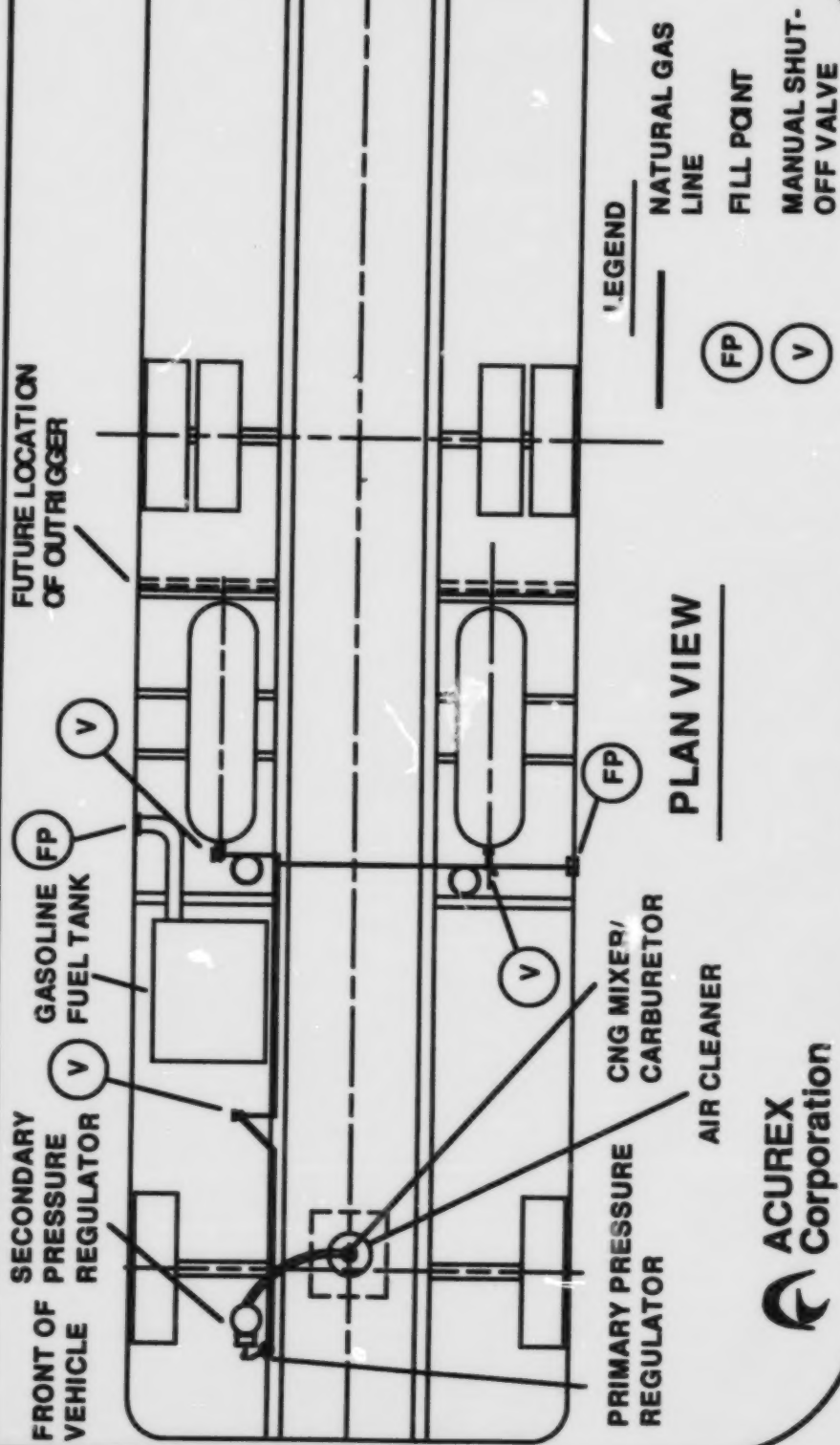


CURRENT PROJECT STATUS

- **Natural gas storage and delivery system design**
- **Prototype vehicle assembly**
- **Chassis dynamometer emission and road performance testing of closed-loop Impco carburetion system**

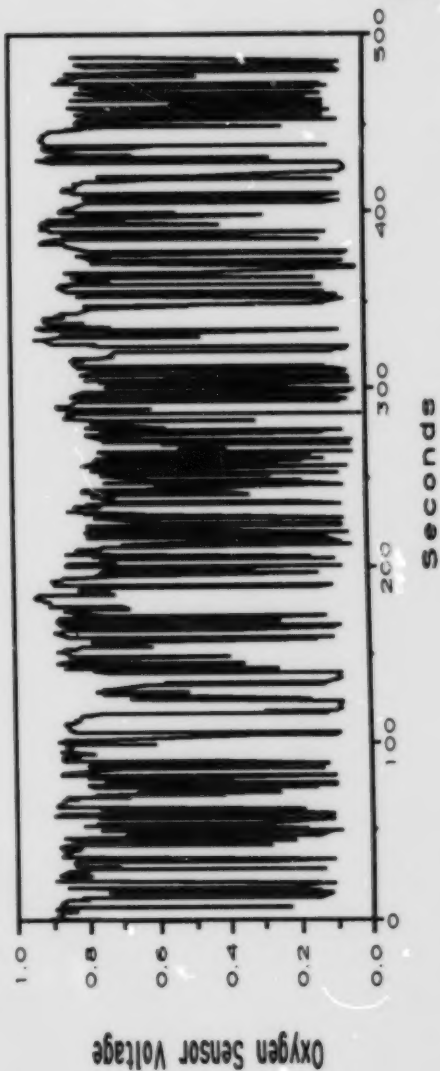
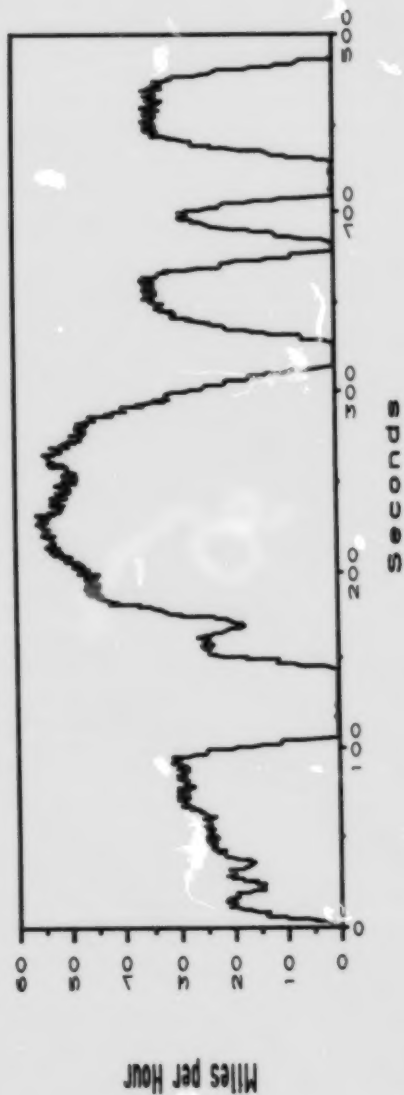


VEHICLE SCHEMATIC



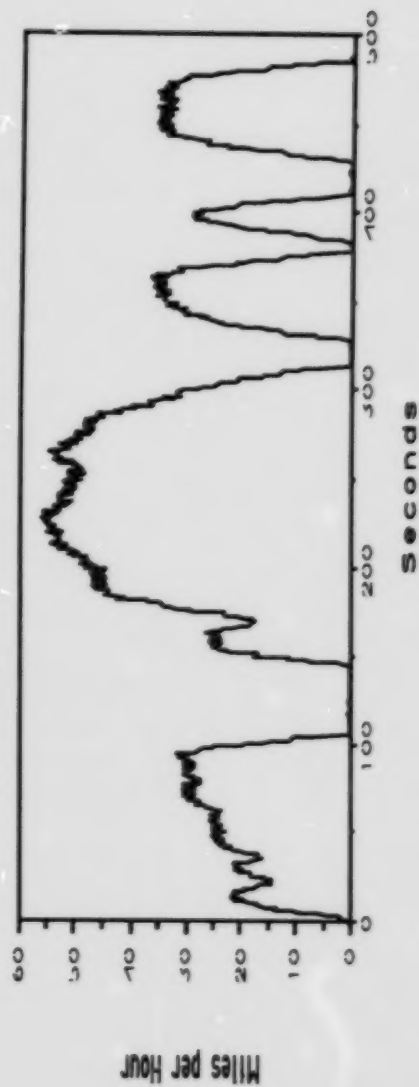
GASOLINE AIR/FUEL CONTROL

Hot 5 Cycles of FTP



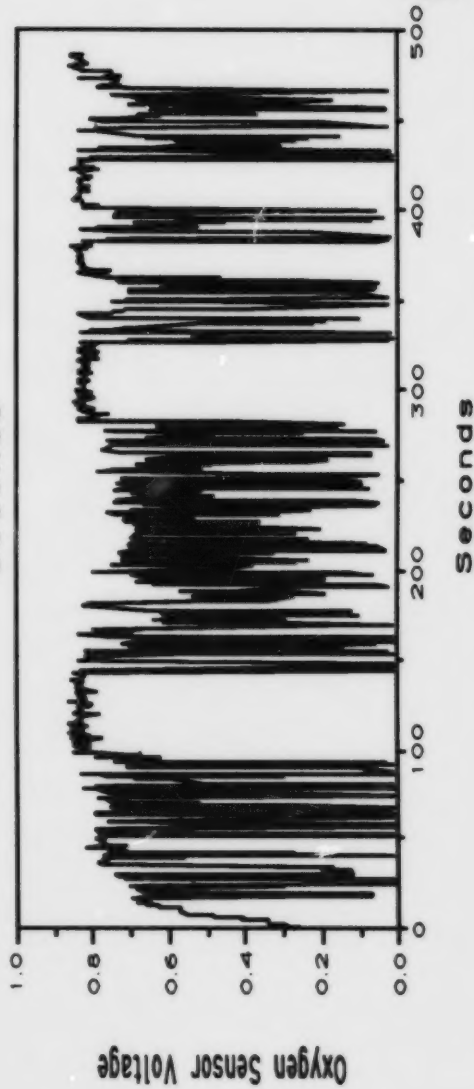
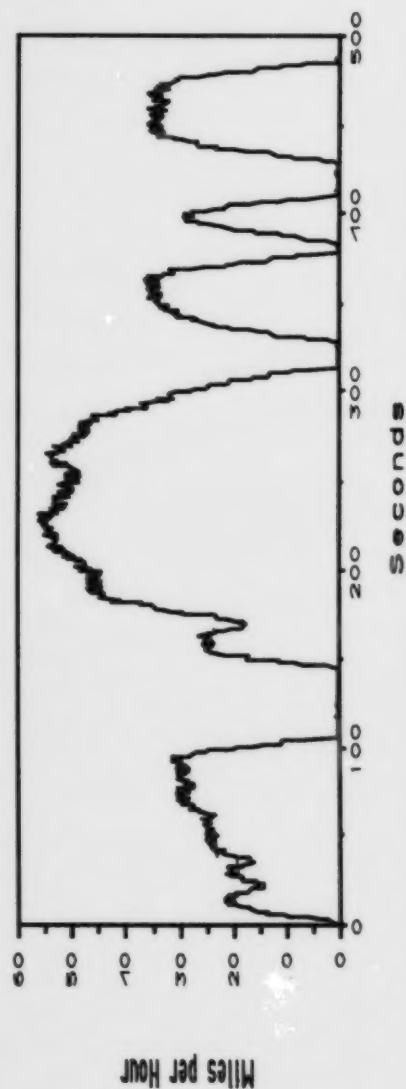
NATURAL GAS AIR/FUEL CONTROL BASELINE

Hot 5 Cycles of FTP



NATURAL GAS AIR/FUEL CONTROL RICH IDLE SETTING

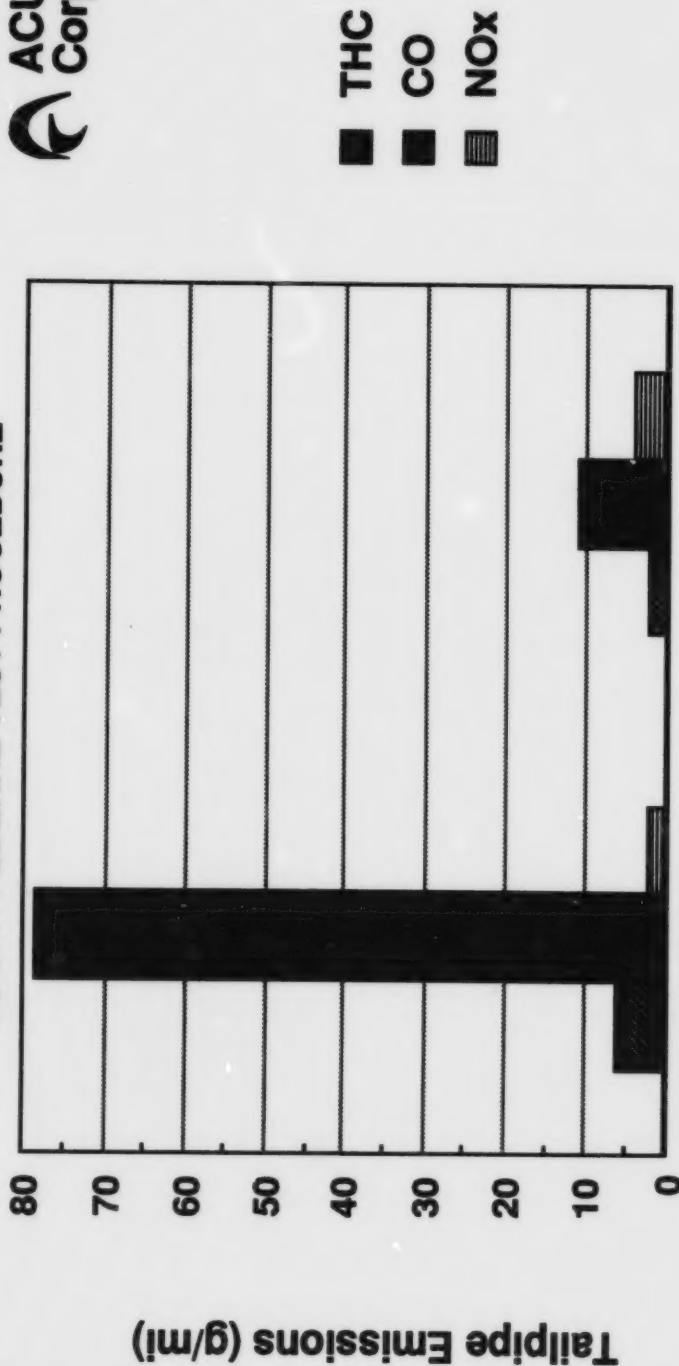
Hot 5 Cycles of FTP



BASELINE TAILPIPE EMISSIONS



US EPA FEDERAL TEST PROCEDURE



Gasoline Baseline NG Baseline

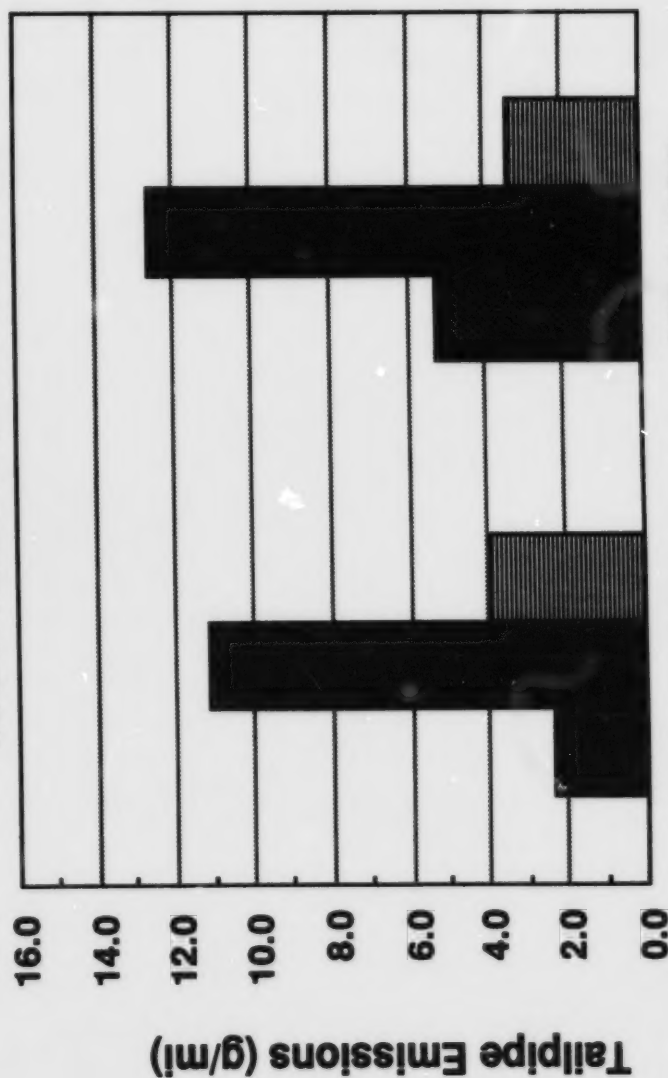
Dynamometer Settings: 8500 lbs, 25 hp
Converter Aged 3700 mi

Note: This test procedure is not applicable for heavy-duty engine emission certification.

NATURAL GAS TAILPIPE EMISSIONS



US EPA FEDERAL TEST PROCEDURE



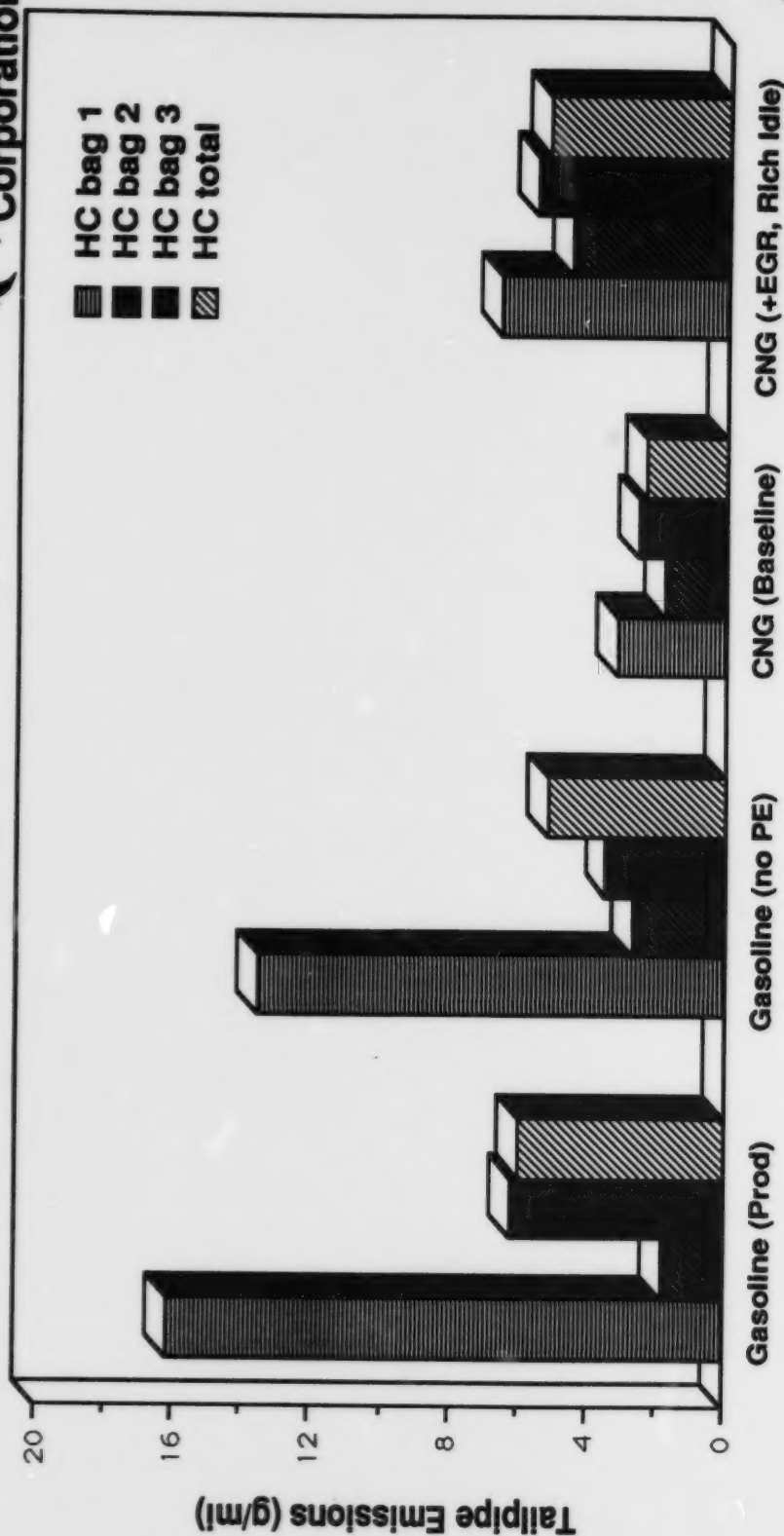
NG Baseline NG & EGR

Dynamometer Settings: 8500 lbs, 25 hp
Converter Aged 3700 mi
Idle Setting: Rich

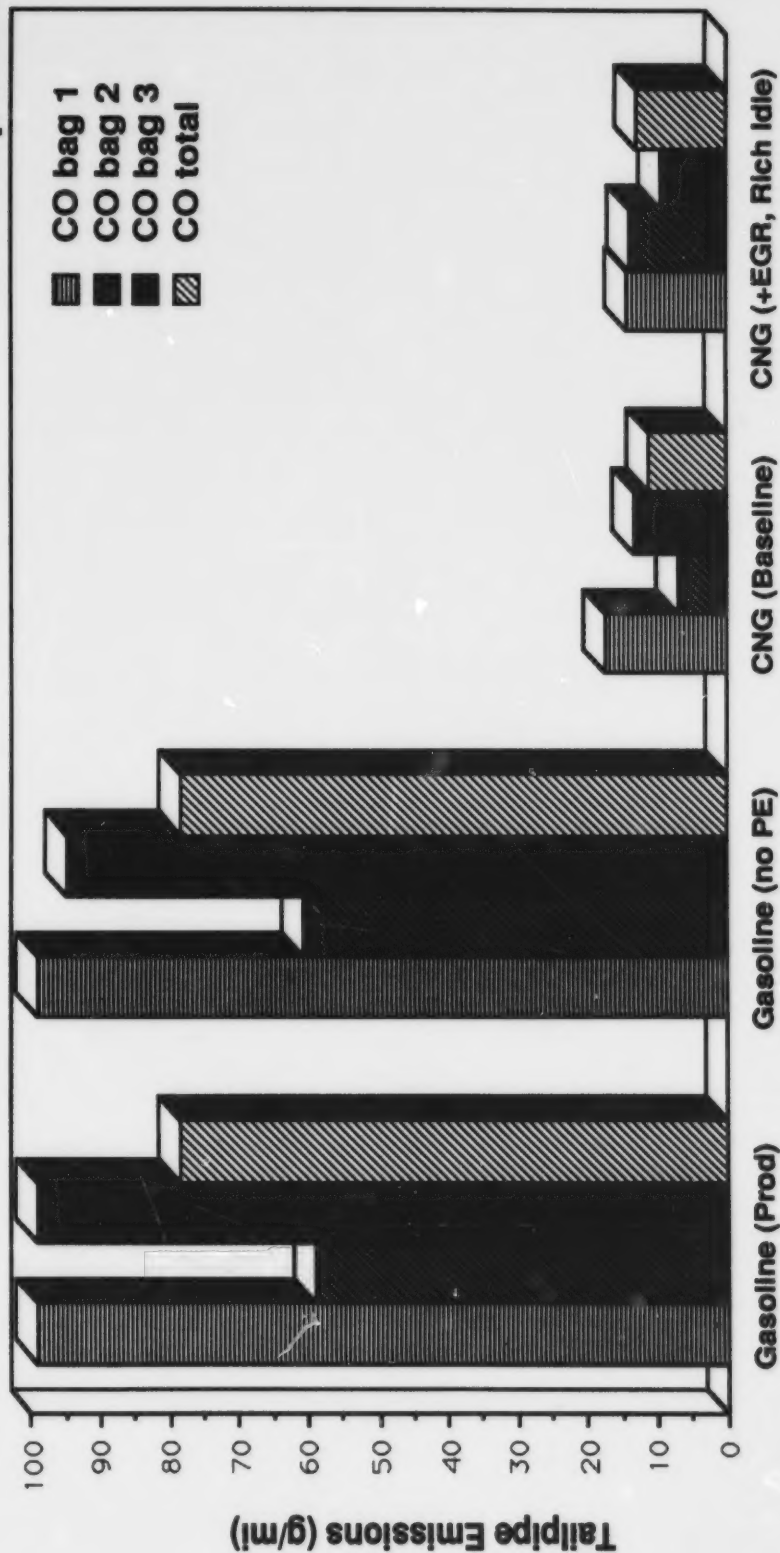
Note: This test procedure is not applicable for heavy-duty engine emission certification.

THC TAILPIPE EMISSION RESULTS - EPA FTP

ACUREX
Corporation

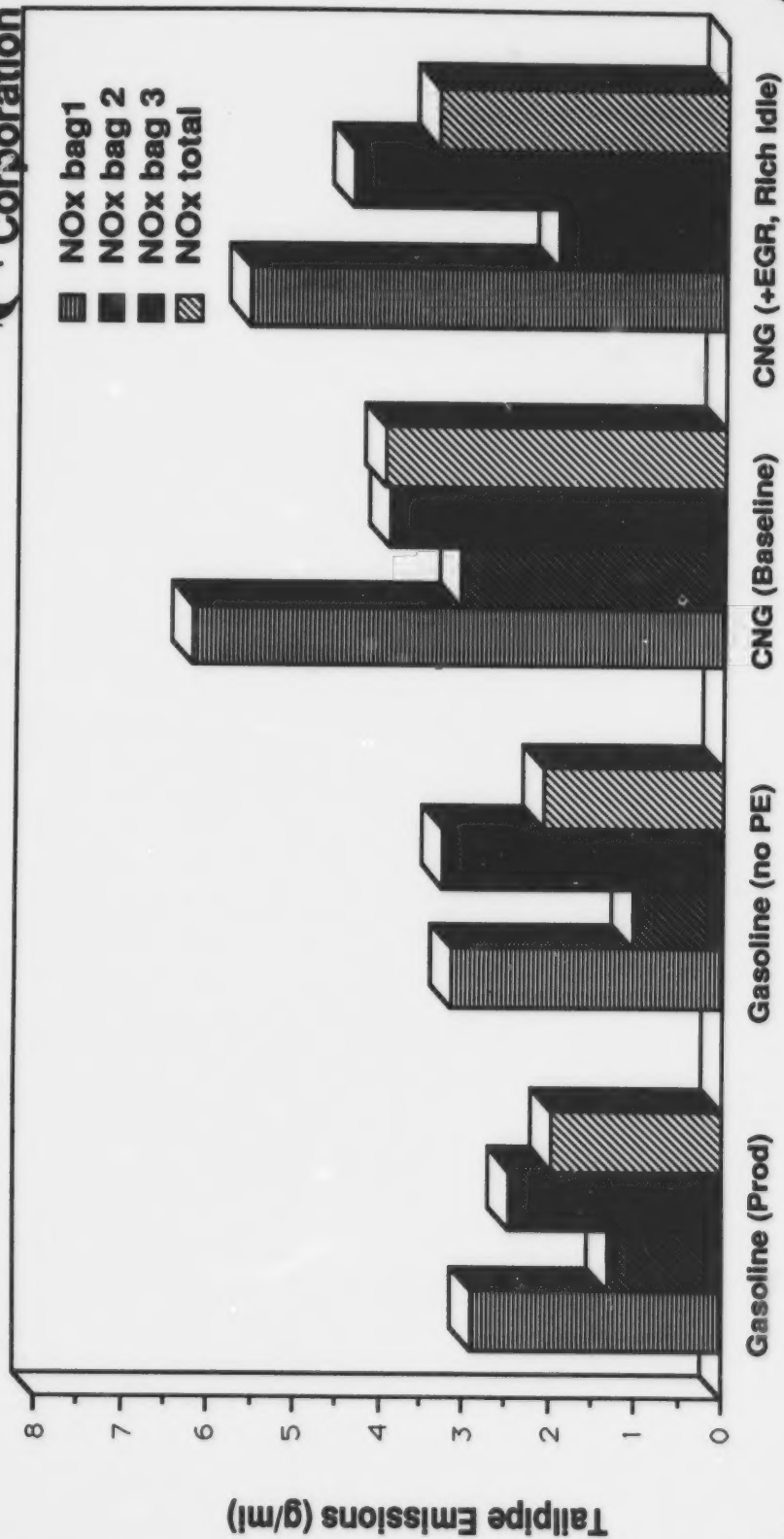


CO TAILPIPE EMISSION RESULTS - EPA FTP



NOx TAILPIPE EMISSION RESULTS - EPA FTP

ACUREX
Corporation



SUMMARY OF EMISSION DATA

Standard Natural Gas Conversion

62% THC Reduction

86% CO Reduction

100% NOx Increase

Natural Gas Conversion with Emission Control

System Changes

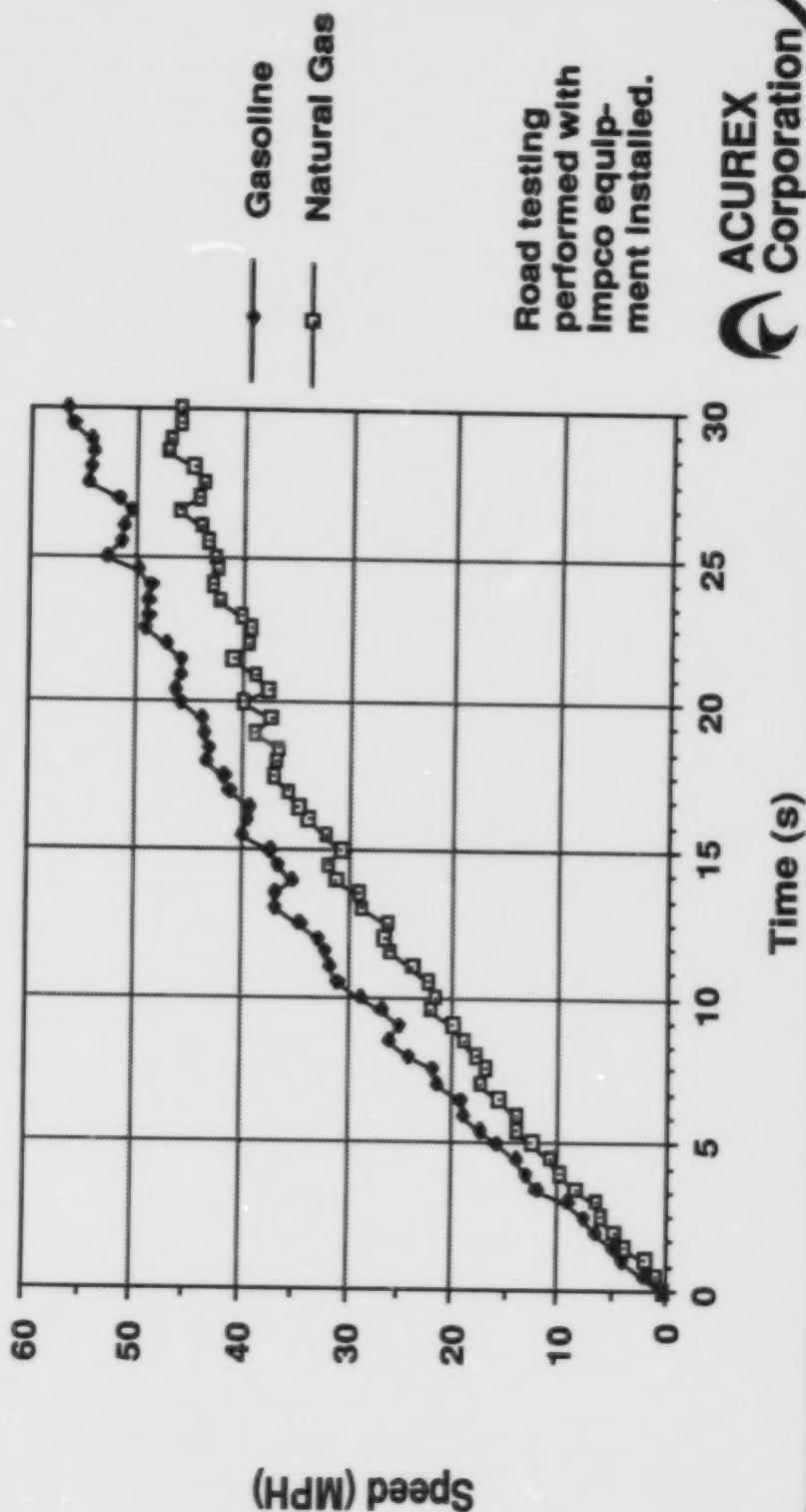
12% THC Reduction

84% CO Reduction

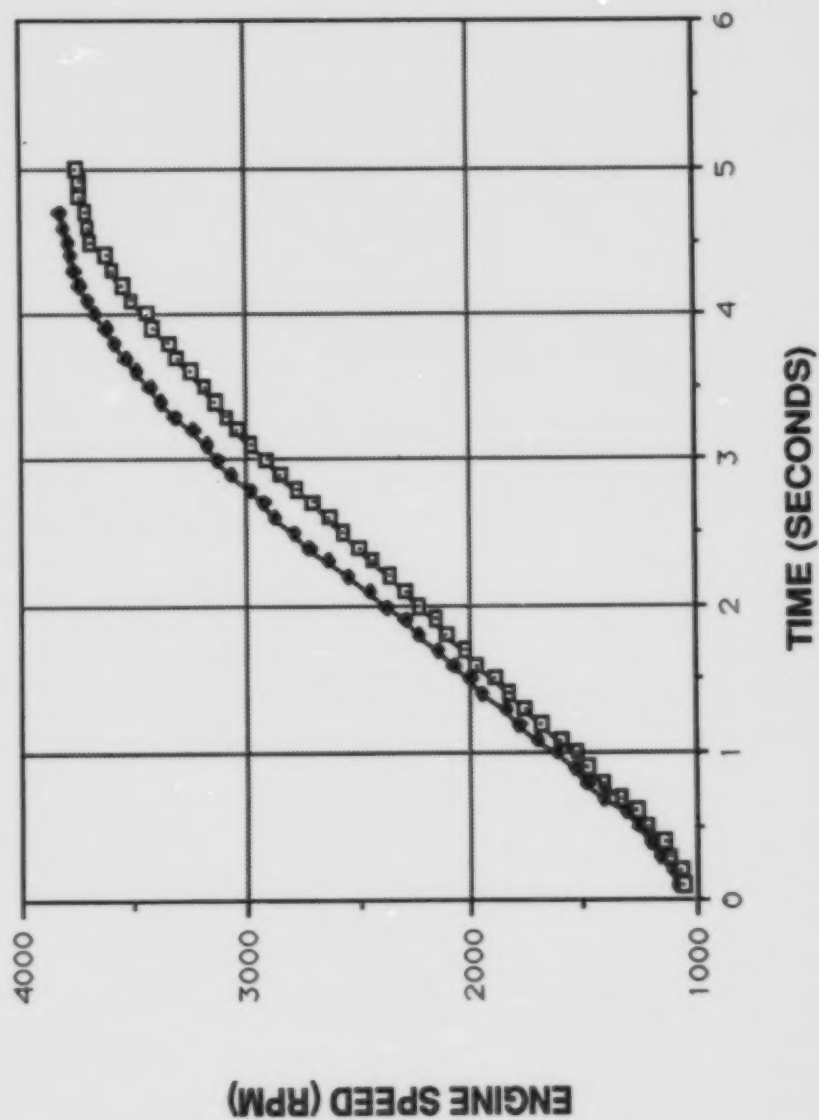
70% NOx Increase



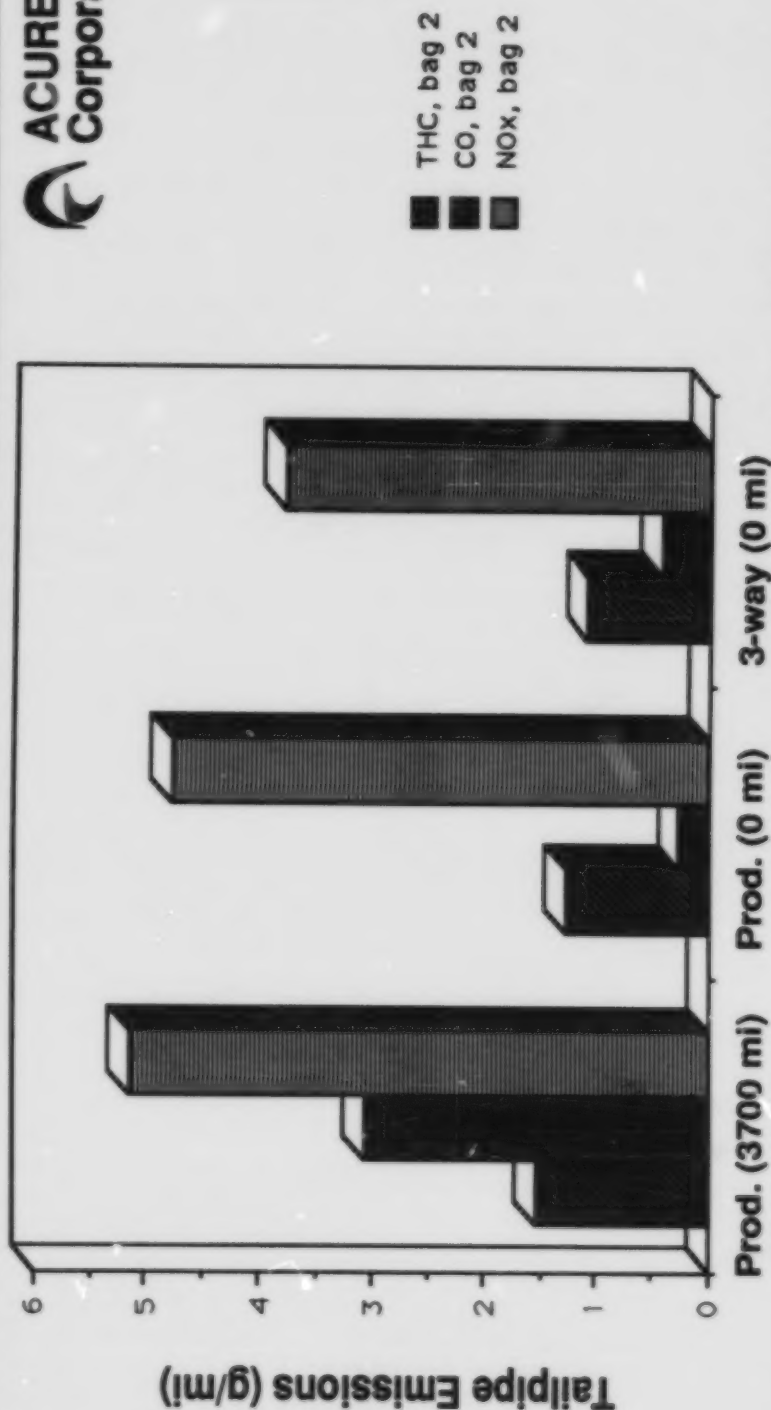
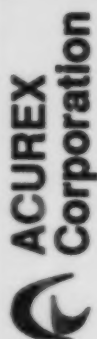
PERFORMANCE-ACCELERATION



PERFORMANCE - ACCELERATION



EFFECT OF CATALYST LOADING ON TAILPIPE EMISSIONS USING NATURAL GAS



Note: This test procedure is not applicable for heavy-duty engine emission certification

Dynamometer Settings: 8500 lbs, 25 hp
Production loading 5/2/0, 5.12 g
3-way loading 4/12/1, 2.65 g

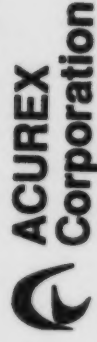
CONVERTER BED TEMPERATURE

- The converter temperature is primarily a function of the air/fuel ratio

<u>Road tests performed at 65 mph</u>	<u>Temperature (°C)</u>
Gasoline (Production, A/F=12)	706
Gasoline (stoich.)	823
Natural Gas (stoich.)	785

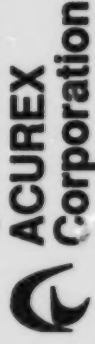
CONCLUSIONS

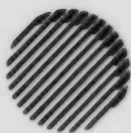
- Acurex has designed and assembled a CNG vehicle prototype emphasizing production feasibility
- Off-the-shelf closed-loop control systems for CNG demonstrate precise air/fuel control
- THC and CO emissions were reduced. However:
 - NOx emissions were increased
 - Performance was reduced
- Limited effort to reduce the NOx emissions of the closed-loop stoichiometric CNG system was partially successful although gasoline levels were not achieved



CONCLUSIONS (cont.)

- Prospects for an optimized closed-loop CNG engine that meets future emission standards are limited due to NOx levels. Further development efforts should include:
 - Extensive engine mapping on an engine dynamometer to optimize the EGR and spark calibration
 - Improved three-way catalyst materials
- The lean-burn approach under development by Acurex offers the potential for achieving future low emission standards while maintaining performance comparable to gasoline.





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1990 WINDSOR WORKSHOP ON
ALTERNATE FUELS
June 11-14, 1990

GASEOUS FUEL INJECTION (GFI) OF NATURAL GAS & PROPANE: AN UPDATE

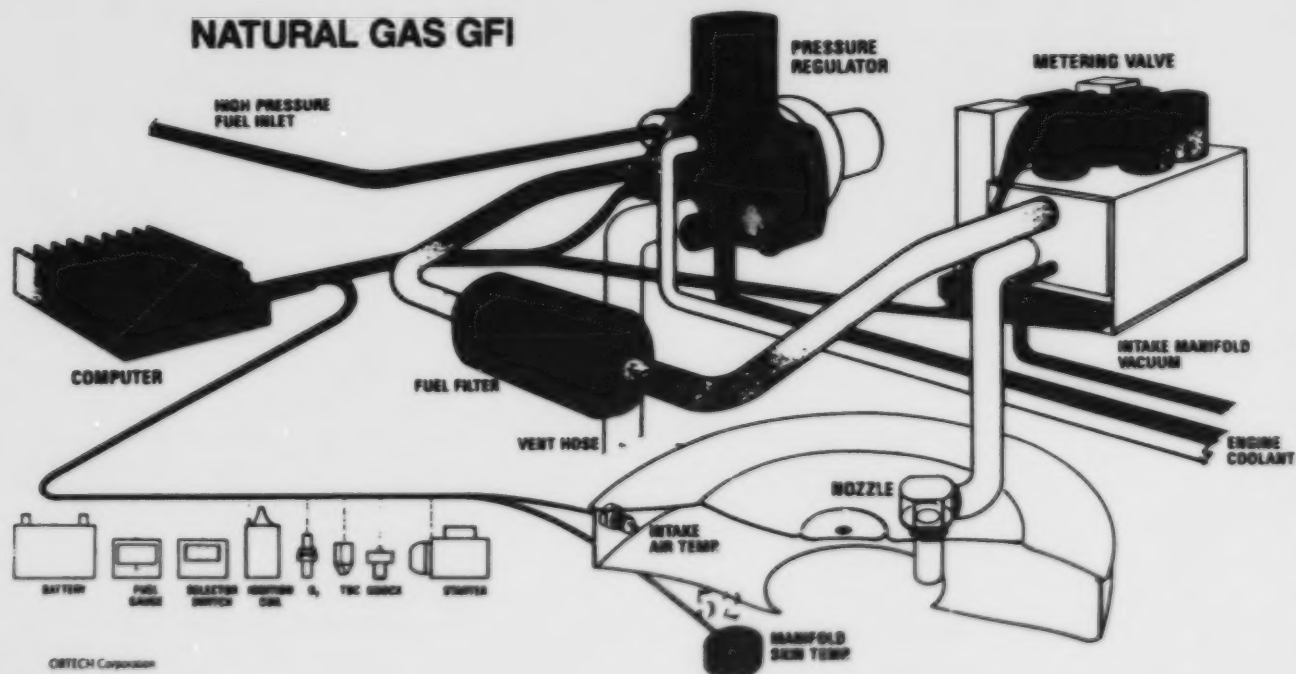
Stephen A. Carter, Bryan C. Williamson,
Karl H. Kozole, Michael A. Knappers.

Two years ago, we proposed a paper on a universal Gaseous Fuel Injection (GFI) concept. Last year, we presented a paper on the GFI theories and hardware that had been developed. This year's paper provides an update on the hardware and software and discusses vehicle results.

Briefly, the GFI system controls fuel flow, spark angle and the dashboard fuel gauge. The system is designed for NGV or LPG/propane fuelling of gasoline engines in the range of 1.0 - 8.2 Litres or diesel-type engines in the range of 50 - 400 BHP. The system can operate open loop or closed loop, with lean or stoichiometric strategies, and accommodates the presence or absence of EGR, catalysts, and secondary air. It also accommodates naturally aspirated, turbocharged, and supercharged engines.

The system's underhood computer uses the speed density method to calculate intake airflow. Fuelling occurs in a metering valve containing a series of sonic gaseous injectors. The NGV version nominally operates at 100 PSIG and can deliver 2650 SCFH. The propane/LPG version operates at 15 PSIG and can deliver 1170 SCFH (i.e. the same energy flow rate as with NGV). Both metering valve versions have a very broad dynamic range (typically 150:1). The injectors typically respond in 5 msec, and meter normally from -40° to 120°C, and from 6 - 24 Vdc.

Schematically, the system is conceived as shown below:



Fuel, at pressures up to 3600 PSIG, is routed from the storage cylinder to the inlet of the single stage GFI regulator. Within the regulator, the fuel is filtered to 40 microns, warmed by an engine coolant circuit, passed through a high pressure shut-off solenoid, sensed by a 0 - 4000 psi sensor (for fuel gauge purposes), and regulated to approximately 100 PSIG. The fuel then passes through a 0.5" I.D. rubber hose to a 5 micron filter and on to the metering valve inlet. The computer turns on the proper combination of injectors to produce the required fuel flow. Notably, four of the computer's sensors are embedded in the metering valve: Fuel, Manifold, and Barometric absolute pressures; Fuel absolute temperature. The metered fuel is then routed through another 0.5" I.D. hose to a fuel nozzle in the intake air stream.

To summarize, the computer controls fuel flow directly by controlling the GFI injectors. Spark angle is controlled by intercepting and advancing the OEM TDC signal. The dashboard fuel gauge is controlled by substituting an appropriate signal for the gasoline fuel gauge sensor signal.

Physically, the hardware appears as shown below and on the following 2 pages:

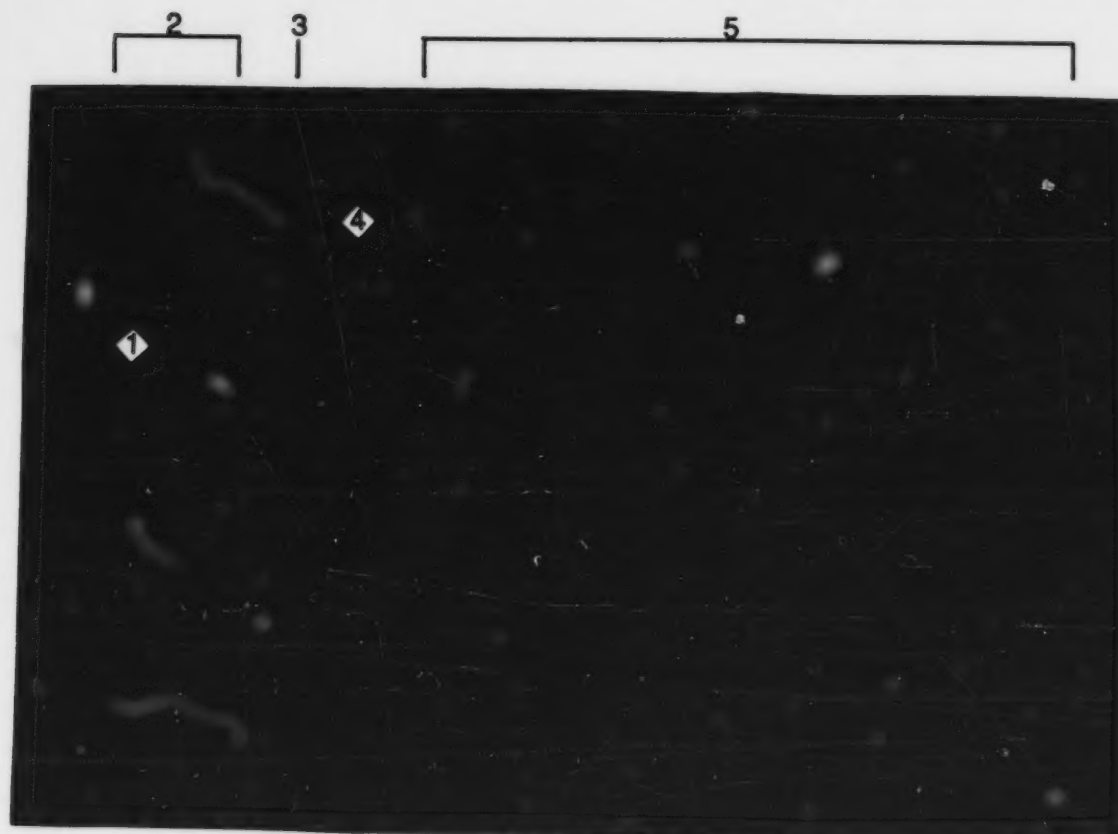


NOTE: Metering valve shown with acrylic see-through body. Actual body is aluminum. Display unit shows 2 high flow injectors (*). Actual unit has 5.

NOTE: Computer shown in acrylic see-through case; actual case is aluminum.

COMPUTER

(See-through Acrylic Case Used to Aid Visualization)

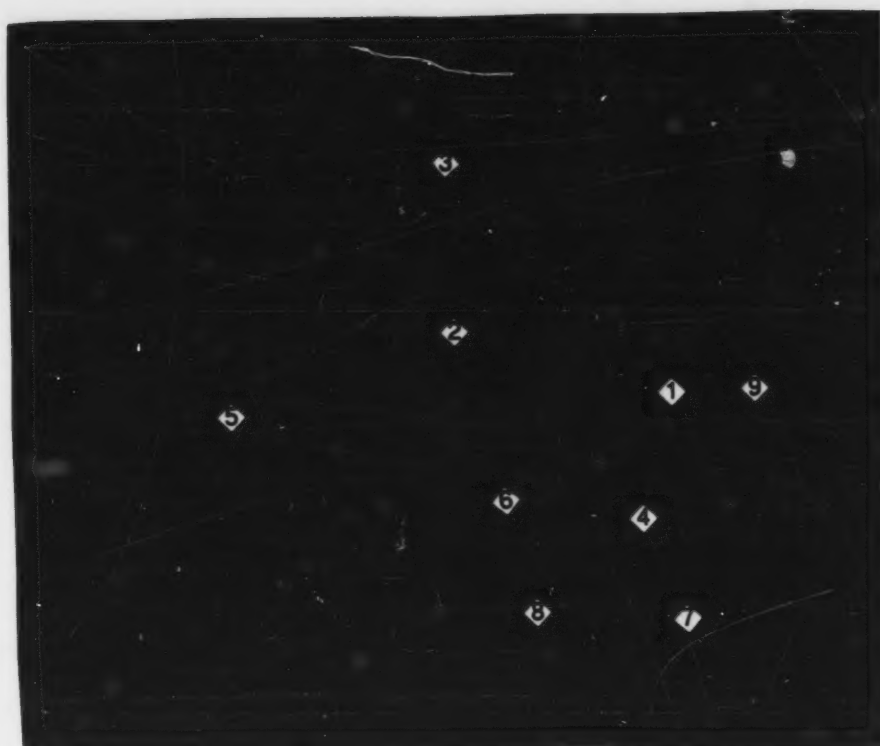


- 1: Harness strain relief & seal.
- 2: Wire bundle exit point
- 3: O-ring seal
- 4: Heat sink
- 5: Computer

METERING VALVE

- 1: Fuel inlet port (1/2" 45° flair)
- 2: Fuel outlet port (1/2" 45° flair)
- 3: MAP hose barb
- 4: #1 injector (low flow)
- 5: #3, #7 injectors (hi flow)
- 6: Harness seal & strain relief



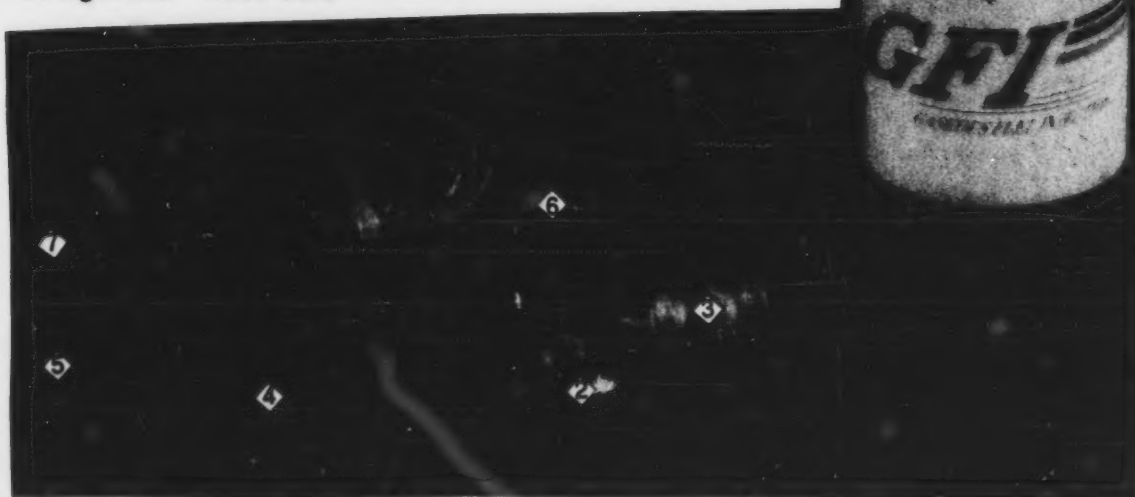


REGULATOR

- 1: Fuel inlet fitting
- 2: 40 micron filter housing
- 3: High pressure solenoid
- 4: Hi pressure sensor
- 5: Regulator area
- 6: Fuel outlet fitting
- 7: Relief valve
- 8: Relief valve outlet
- 9: Coolant fitting

MISCELLANEOUS

- | | |
|-------------------------------|-------------------------------|
| 1: Fuel Filter | 5: 90° flair hose barb |
| 2: Nozzle | 6: Intake air temp. sensor |
| 3: Hose crimp | 7: Manifold skin temp. sensor |
| 4: Straight flair - hose barb | |



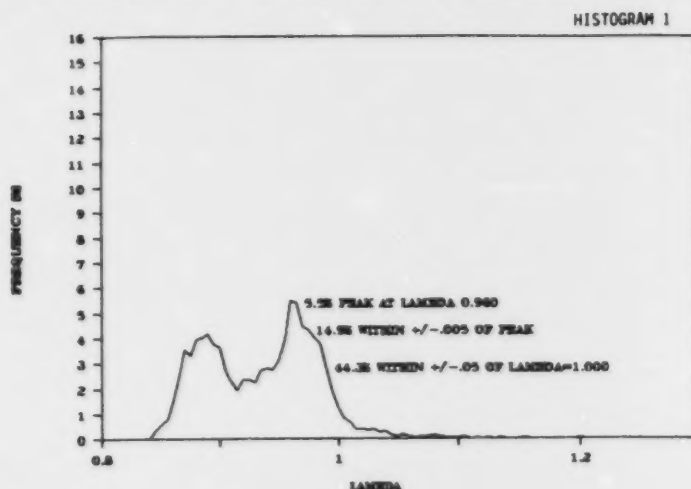
The heart of the system is clearly the computer. The entire calibration and control of the GFI system is accomplished inside the computer. No mechanical parts are adjusted or altered. The system's calibration is accomplished in two portions, as shown below:

FACTORY CALIBRATION: adjusts for 25 factors concerning the engine, the fuel, and GFI production parts variability.

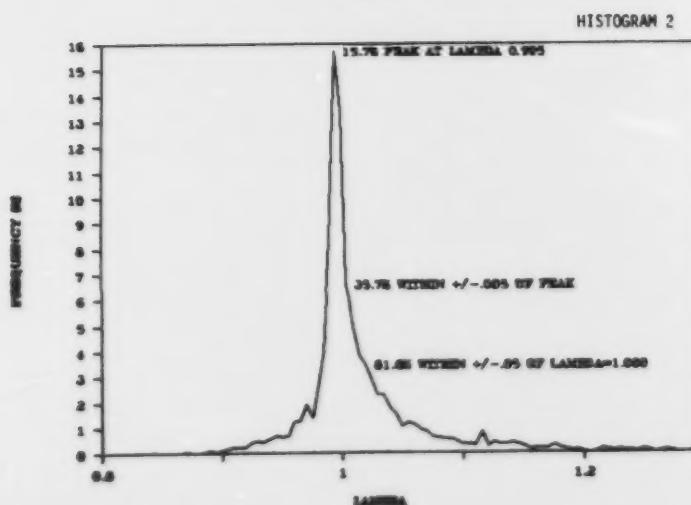
CORRECT ON THE FLY: compensates for 10 factors, including:
3 temperatures, 3 absolute pressures, RPM, exhaust O_2 , estimated EGR rate, estimated throttle position.

The factory calibration can also be installed and/or refined in the field at the point of installation. In that case, a process called "Quick Learn" is used to allow the computer to adapt itself to the specific engine that it is being installed on.

The ability of the Quick Learn process is highlighted in the following series of histograms. These histograms display %-time vs Lambda as the vehicle is driven through the HOT 505 portion of the Federal Test Procedure. Thus, a perfect system would have a histogram with 100% of the time at stoichiometry (i.e. Lambda = 1.0).



Performance with
universal program
only.



Performance after
QUICK LEARN
process completed.

As a rule of thumb, if the spark angle is not advanced in the NGV mode, the power loss will double (i.e. 12% "ideal" power loss will be 24% if spark angle is left unchanged at the gasoline timing). The GFI system uses a universal algorithm to determine what instantaneous incremental advance is needed.

Exhaust emissions have been tested on a number of GFI equipped vehicles. The general trend is that CO and fuel economy improve, NOx is very similar to gasoline levels, and total hydrocarbon increases dramatically. The non-methane HC results have not been quantified to-date, but are expected to be lower than on gasoline. Perhaps more pointedly, the GFI equipped vehicles are all well below the current emissions law levels, with a healthy safety margin. Results on 4 vehicles are shown below:

<u>Vehicle</u>	<u>Inertia Wt - Lbs</u>	<u>Test HP</u>	<u>Cold-Start Fed. Test Procedure (FTP) NGV-mode emissions levels (gr/mi)</u>			
			<u>Est'd. nmHC</u>	<u>Tot. HC</u>	<u>CO</u>	<u>NOx</u>
5.7L Van	4500	16.2	0.18	1.47	0.5	0.49
5.7L Van	4500	16.2	0.19	1.50	3.2	0.44
4.3L S-10	4500	16.2	0.22	1.73	1.4	0.69
4.3L S-10	3500	11.4	0.21	1.64	2.9	0.47

Note: All vehicles are current model year and have three-way catalysts, no secondary air, and use EGR.

A notable impediment to FTP emissions testing has been the gasoline system's charcoal canister. The canister captures and recycles evaporative losses. To an aftermarket fuelling system, such as GFI, the canister is an unknown and uncontrollable fuel source. As such, it adds errors to instantaneous fuelling and temporarily "corrupts" the long-term adaptive memory.

The magnitude of the NGV-mode fuelling errors caused by the canister vary greatly based on the vehicle's prior usage (i.e. driving cycle and amount of time on gasoline). On late model vehicles, using three-way catalysts and NO secondary air, the fuelling errors from canister effects can cause extreme shifts in tailpipe emissions.

Therefore, in order to get meaningful results, it is necessary to either establish a canister conditioning system, or to run with the canister disconnected. Notably, canister conditioning adds significantly to the time required to conduct a given test series. Furthermore, the variability between OEM's on canister conditioning cycles makes it difficult to select a simple and consistent procedure. Accordingly, we elected to disconnect the canister for all emissions testing.

Histogram 1 shows that the engine can be run on the universal program, albeit with a rather wide metering characteristic. Histogram 2 shows that after performing the Quick Learn process the system has matched itself quite well to the engine and spent ~13% of the time at $\Lambda = 0.995$. Tests on three engine types have all shown that the NGV/GFI and gasoline histograms are quite similar in shape and accuracy of the metering.

Notably, the OEM gasoline systems often have better accuracy in transients and during the warm-up transition periods. The key factors affecting this are related to the GFI aftermarket version having the following compromises which would not exist in an OEM system:

The OEM system knows the EGR rate while GFI estimates it
(Note: In the future, GFI may sense whether EGR is on or off.)

The OEM system "anticipates" transients by sensing throttle position, whereas the GFI aftermarket version estimates transients from the rate of change of manifold pressure.

Power loss is another factor used to evaluate ATF systems. Some power loss on NGV is inevitable due to the fuel displacing intake air, the negative work associated with advancing the NGV timing, and the slower burn rate of the NGV combustion charge. Convention has generally accepted this power loss to be in the range of 12 - 15%. Power tests on GFI equipped vehicles have generally confirmed those expectations. Pointedly, the 12 - 15% NGV-mode power loss with GFI was achieved "automatically", without fine tuning the system on a chassis dyno. Actual results are shown below:

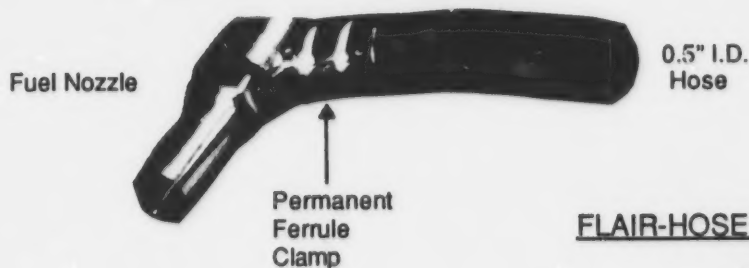
Natural gas composition (i.e. test fuel chemistry)	95.7% methane 2.0% other HC's 1.9% nitrogen 0.4% carbon dioxide
Specific gravity	0.575 vs air density
Stoichiometric air/fuel ratio	16.37:1

<u>Test Vehicle</u>	<u>Chassis Dyno Power Output (wheel-HP)</u>		<u>Power Loss</u>
	<u>Gasoline</u>	<u>NGV/GFI</u>	
3.1L V-6 MPFI Lumina	89	79	11.2%
4.3L V-6 TBI G-Van	108	91	15.7%
5.7L V-8 TBI G-Van	140	122	12.9%

With society's increasing focus on the environment, more attention is being directed at non-exhaust sources of emissions. Such sources include refill and running losses, evaporative emissions, and general leakage emissions. Notably, any fuelling system has the potential to emit fuel through leaking connections and seal faces. As gases are more difficult to seal than liquids, such sources within the GFI system were evaluated to determine what impact they might have.

One such leakage source is plethora of hose connections used in a fuelling system. Conventional hose barb joints were found to be leak prone when clamped with conventional worm-gear hose clamps. After some development, ORTECH settled on a crimped ferrule type of clamp which provides gas tight sealing from -40° to $+120^{\circ}\text{C}$. The resultant joint is less expensive and, since it is "permanent", is tamperproof. In order to facilitate servicing with this permanent joint, the hose barb terminates in a 45° SAE inverted flair fitting. The flair fitting allows the hose to be removed/repositioned /retightened multiple times without disturbing the hose to barb interface. In order to seal the flair fitting gas tight, a standard copper sealing washer is used. The appearance of the ferrule clamp is shown in the following photo:

FERRULE HOSE CLAMP



FLAIR-HOSE BARB FITTINGS



Another such leakage source is the injector-piston to metering-orifice seal. There are seven such seals in the NGV metering valve and eight in the propane valve. Durability tests show that these points total zero leakage on a new valve and perhaps 70 SCCH by the end of the metering valve's useful life. At the rate of 70 SCCH, the total injector seat leakage might represent .02% of a typical engine's idle flow requirement . . . and would thus not materially affect the accuracy of the fuel metering when the engine was operating. Or, from another perspective, assuming the average urban driver and counting this leakage as an evaporative source, the loss to the atmosphere when the engine was shut-off would represent an equivalent burden of .001 gr/mile of HC. Thus, such losses are much lower than are emitted by gasoline system.

From the regulatory side, it is notable that the Canadian Gas Association's standard for NGV systems permits leakage rates up to 200 SCCH. ORTECH believes that the CGA rate is reasonable and should be maintained. The 200 SCCH rate assures that leakage cannot produce offensive odours nor create combustible mixtures in closed garages. Standards significantly lower than 200 SCCH are not required and may not be achievable across all production and for the life of the "system".

The GFI system has undergone significant durability testing. In fact, the metering concept embodied in the GFI system (patent pending) is aimed at maximizing injector life. The following chart shows the current projections for life expectancies of the 5 highest flow injectors:

<u>Driving Cycle Model</u>	<u>Estimated Injector Life in Miles</u>	
	<u>NGV</u>	<u>LPG</u>
100% FTP driving cycle	3.1M	4.1M
100% HOT 505 driving cycle	1.0M	0.4M

The propane version of the GFI system has been rigorously tested for its tolerance of oily waxy residues (OWR) and black magnetic residues (BMR). The injectors, in particular, underwent significant finessing to make them tolerant of the OWR at low temperatures ($<-20^{\circ}\text{C}$). The resultant final design is quite tolerant of OWR (with or without BMR), and other high viscosity fluids.

The BMR was found not to be an issue, other than at extraordinarily high contamination rates (i.e. 5000 ppm contaminant), and with the system's filter omitted. In that case, the BMR's high specific gravity (~5) would cause it to "precipitate out" of the fuel flow stream at any point in the fuelling system where the flow direction changed or the velocity dropped. This dropping out phenomenon is due strictly to mass density considerations and is unrelated to the BMR's magnetic character. The final metering valve and injector design is such that a conventional LPG/propane vapourizer fills up and clogs shut from BMR at about the same rate as the GFI metering valve. Thus, the GFI system is at least as tolerant of BMR as current conventional vacuum/pneumatic systems.

Testing to date has shown that the GFI metering valve tolerates fuel contaminated with both 500 ppm BMR/500 ppm OWR and 1000 ppm BMR/1000 ppm OWR with no significant degradation in fuel metering down to -40°C .

The GFI system is currently being prepared for a field evaluation project which should begin in August and will include the following phases:

- 6 vehicles in utility company service for 1 year
- 3 vehicles for 50K miles emissions durability testing
- 2-3 vehicles for OEM evaluation in Kapuskasing, Denver, Phoenix
- 2-3 vehicles for lab reference use
- 5 vehicles in school bus service for 1 year.

Note: The engines in this project include:

- 3.1L V-6 multipoint fuel injection
- 4.3L V-6 throttle body fuel injection
- 5.7L V-8 " " " "
- 7.4L V-8 " " " "

Regular production availability of the kit is expected during, or soon after, this field evaluation project.

**SESSION 1 - LIGHT/MEDIUM DUTY VEHICLES
B - EMISSIONS**

Co-Chairs: R. Neville, ORTECH International
R. McGill, Oak Ridge National Laboratory

**"Auto/Oil Air Quality Improvement Research Program
Why? What? How? Where? and When?"**

Joseph M. Colucci
Fuels and Lubricants Department
General Motors Research Laboratories
Co-Chairman, Research Planning Task Force
Auto/Oil Program

To be Presented at
1990 Windsor Workshop on Alternative Fuels
Toronto, Ontario, Canada
June 11, 1990

ABSTRACT

Major auto and oil companies are cooperating on a program to obtain data on the potential reductions in vehicle emissions and improvements in ozone air quality obtainable from reformulated gasolines and methanol. This is the largest program of this type ever attempted. Phase I of the program is looking at the impacts of gasoline properties (aromatic, olefin, oxygenate-MTBE, ETBE, ethanol-, and sulfur contents, RVP and 90 percent distillation temperature) on vehicle emissions (exhaust, evaporative and running losses on mass and composition speciated bases). Twenty 1989 model and 14 1983-1985 model vehicles are being tested. In addition three different fuels (M0, M15 and M85) are being tested in 20 prototype VFV and FFV vehicles.

Ozone air quality modeling will be done for three cities (Los Angeles, New York and Dallas-Fort Worth) for short-term and long-term (1995 and 2005-2010, respectively) scenarios using results from the emissions testing. Economic analyses will determine the costs of the reformulated and methanol fuels, and their cost effectiveness in contributing to atmospheric ozone reduction.

The Program is ongoing. Plans are to start release of results later this year, with complete results available about a year from now. A Phase II Program, to expand on the results from Phase I, is being planned.

**Auto/Oil Air Quality Improvement
Research Program -
Why? What? How? Where? and When?**

64

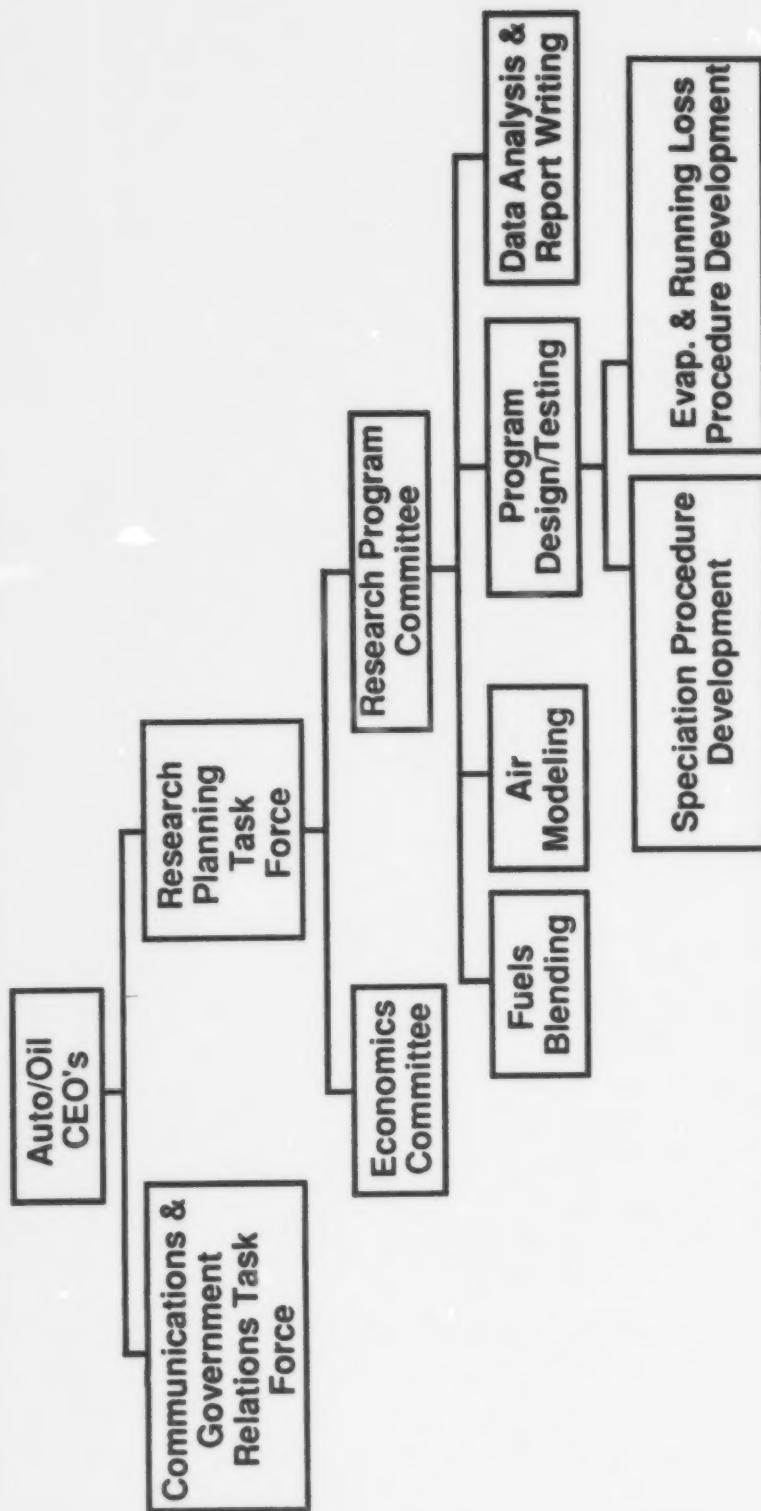
**Joseph M. Colucci
Fuels And Lubricants Department
General Motors Research Laboratories
Co-chairman, Research Planning Task Force
Auto/Oil Program**

AUTO/OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM

BACKGROUND

- **Federal Clean Air Act Deadline Has Passed for Achieving NAAQS**
- **Ozone Nonattainment in Many Urban Areas**
- **Federal and State Legislative and Regulatory Initiatives**
- **Reformulated Gasoline/Modified Vehicle Option Needs to be Addressed Along With Alternative Fuels (e.g., Methanol)**

ORGANIZATION



PARTICIPANTS

Oil Companies

Amoco	Marathon
ARCO	Mobil
Ashland	Phillips
BP America	Shell
Chevron	Sun
Conoco	Texaco
Exxon	Unocal

Auto Companies

Chrysler
Ford
General Motors

Provision Made for Associate Membership

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Princeton

Economics

Dr. Robert Hahn

**American Enterprise
Institute**

OBJECTIVES

- Define and Conduct a Test Program That Will Develop Data Regarding the Potential Reduction in Total Vehicle Emissions and Improvements in Air Quality, Primarily Ozone, From:
 - Reformulated Gasoline Producible in Volume from Existing Refineries and Usable in Existing Vehicles (Phase I)
 - M85 in Currently Available FFV's (Phase 1)
 - Future Gasolines Producible in Volume with Refinery Changes and Vehicle System Changes (Phase II)
 - Various Other Vehicle/Fuel Systems (Phase II)
- Examine the Relative Cost Effectiveness of the Above Vehicle/Fuel Systems in Improving Air Quality

PHASE I PROGRAM SUMMARY

	Priority	Timing		Cost,\$MM
		Start	End	
1	Current Vehicles/ Reformulated Gasolines ¹ Flexible Fuel Vehicles/ M85, M10, M0	April 15	- August 31, 1990	4.6
		April 1	- June 30, 1990	1.1
2	Older Vehicles/ Reformulated Gasolines ¹	April 15	- August 31, 1990	3.1
3	Current Vehicles/ Reformulated Gasolines ²	September 1	- December 31, 1990	2.5
4	Current Vehicles/ Sulfur Effect	January 1	- February 28, 1991	0.9
	Air Modeling	January 1, 1990	- March 31, 1991	0.8
	Economic Evaluations	December 1, 1989	- March 31, 1991	1.3
	Analysis and Reporting	January 1, 1990	- April 30, 1991	0.2
		September 1, 1989	- April 30, 1991	14.5

¹Gasoline Variables - Aromatics, Olefins, T₉₀, MTBE

²Gasoline Variables - Composition A/O/T₉₀, RVP, Ethanol, ETBE

PHASE I MATRIX SUMMARY

Matrix	Vehicles	Fuels	Test Site
A	New Models	16 Reformulated gasolines + Ind. Avg. + Cert (Aromatics, Olefins, MTBE, T ₉₀)	GM - MPG
B	Prototype Flexible Fuel	Ind. Avg. gasoline M10, M85	Ford - CTL
C	Older Models	16 Reformulated gasolines + Ind. Avg. + Cert. (Aromatics, Olefins, MTBE, T ₉₀)	Ford - CTL
D	New Models	9 Reformulated gasolines (Ethanol, ETBE, RVP)	Ford - CTL
E	New Models	Sulfur Level	GM - MPG

TEST FUELS - MATRIX A AND C

MVMA Fuel Survey Data

	Min.	10th Perc.	50th Perc.	90th Perc.	Max.
Aromatics, %	14.7	23.8	31.5	40.8	53.6
Olefins, %	0.6	4.0	10.5	17.7	37.0
90% Point, °F	301	318	337	346	350
Sulfur, ppm	10	70	290	650	1170
MTBE, %					

Program Target Levels

Low	Ind. Avg.	High
20	32	45
5	12	20
280-300	335	350-360
	300	
0	0	15

July 1988 All Unleaded Grades

BLENDING GUIDELINES

9 RVP

$T_{50} = 240^{\circ}\text{F}$ Max.

300 ppm Sulfur
(Industry Average)

Typical Refinery Blend
Components

1.6% Benzene
(Industry Average)

Attempt to Hit 280°F and 360°F T_{90}

87 (R+M) / 2 Min.

Durability Fuel Additive Package

Driveability Index =
1250 Max.

Antioxidant

TEST FUELS - MATRIX B

- **M0 - Industry Average Gasoline**
 - Aromatics 32%
 - Olefins 12%
 - 90% Point, °F 335
 - MTBE 0%
- **M10 - 90% Industry Average Gasoline**
 - 10% Fuel Grade Methanol
- **M85 - 15% Industry Average Gasoline**
 - 85% Fuel Grade Methanol
 - Adjusted to 9 psi RVP with Butane

TEST FUELS - MATRIX D

- 2³ Factorial (3 Gasoline Variables, Each at 2 Levels) Plus One ETBE - Containing Test Gasoline
- 9 Test Gasolines (2 of Which are Already in Earlier Matrix) Durability Fuel Additive Package

Target Levels		
Low	Industry Average	
20/5/280	32/12/335	
8 (9 ¹)	9 (10 ¹)	
0	10	

Composition_{A/O/T₉₀}
 RVP, psi
 Ethanol, %
 10% Ethanol Blends

Plus: 20/5/280/17 A/O/T₉₀ /ETBE at 9 RVP

TEST FUELS - MATRIX E

Target Sulfur
Level, ppm

Certification Test Fuel

40

Spiked w/ t-Butyl Disulfide

500

NEW VEHICLE SELECTION CRITERIA

<u>Domestic and Foreign</u>	<u>No. of Vehicles</u>
High Production Volume	6 Domestic Car Models
Low Emissions	x 2 = 12 Cars
Representative of Early-Mid 90's Technology	2 Domestic Truck Models
1989/90 MY	x 2 = 4 Trucks
10,000 Miles Minimum	
<u>Foreign</u>	
Low In-Use Emissions	2 Import Car Models
High Production Volume	x 2 = 4 Cars
	<u>Total 20 Vehicles</u>

DESCRIPTION OF PROTOTYPE FLEXIBLE FUEL VEHICLES

Manufacturer	Model	Engine	Fuel System	EGR	Converter	Comments
Chrysler	Spirit	2.5	SFI	No	3-Way**	Flex. Fuel
Chrysler	Caravan	2.5	SFI	No	3-Way	Flex. Fuel
Ford	Crown Vic.	5.0	PFI	Yes	3-Way	Flex. Fuel
Ford	Taurus	3.0	PFI	Yes	3-Way	Flex. Fuel
GM	Corsica	2.8	PFI	Yes	3-Way	Var. Fuel
GM	Lumina	3.1	PFI	Yes	3-Way	Var. Fuel

**Close coupled; all others under floor
All models have adaptive learning

OLDER VEHICLE SELECTION CRITERIA

- 1983 - 1985 Model Years
- 50,000 - 80,000 Miles
- Mixture of Adaptive and Non-Adaptive
- Cross-Section Representative of Cars on the Road
 - 4 Domestic Car Models x 2 = 8
 - 1 Import Car Model x 2 = 2
 - 2 Domestic Truck Models x 2 = 4
 - Total 14 Vehicles
- Automatic Transmission
- High Sales Volume

EXHAUST EMISSION MEASUREMENT

- Mass Emissions
 - Federal Test Procedure
 - Plus Engine Out Emissions and Modal Data (Except for Alternate Fuel Vehicles)
- Species
 - 137 Hydrocarbon Species
 - 12 Aldehyde Species
 - 4 Oxygenate Species

Note: For All Matrices Except For Sulfur (Mass Only)

EVAPORATIVE EMISSION MEASUREMENT

- Mass Emissions
 - Federal Test Procedure
 - Hot Soak
 - Diurnal
 - Impinger for FFV Fleet CH₃OH Measurement
 - Species
 - 137 Hydrocarbon Species
 - 4 Oxygenate Species
 - Model
 - Proprietary GM Vapor Generation Model Used to Predict Mass and Species for Tests When Evap Emissions are not Measured

Note: For All Matrices Except For Sulfur (Mass Only)

RUNNING LOSS EMISSION MEASUREMENT

- Mass Emissions
 - No Federal Test Procedure
 - 3 Consecutive Urban Dynamometer Driving Cycles Separated by a 2-Minute Idle
 - Point Source Measurement Technique
 - Impinger for FFV Fleet CH₃OH Measurement
- Species
 - 137 Hydrocarbon Species
 - 4 Oxygenate Species
- Model
 - Proprietary GM Vapor Generation Model Used to Predict Mass and Species for Tests When Evap Emissions are not Measured

Note: For All Matrices Except For Sulfur (Mass Only)

DESIGN OF AIR QUALITY MODELING FOR THE AUTO/OIL PROGRAM

Alan M. Dunker
*Environmental Science Department
General Motors Research Laboratories*

Objective of the Modeling

To Assess the Air Quality Impact in Urban Areas of Using
Gasolines of Varying Composition, Methanol Fuels, and
Ethanol Blends in Light-Duty Vehicles

CONTRACTORS

- Primary Contractor

- Systems Applications, Inc.*

- Development of Emission Inventories, Application of Models, and Overall Coordination

- Secondary Contractors

- Radian Corporation*

- Selected Aspects of Developing Emission Inventories, Application of Models for One City

- Sonoma Technology Inc.*

- Implementation of Atmospheric Chemical Mechanism

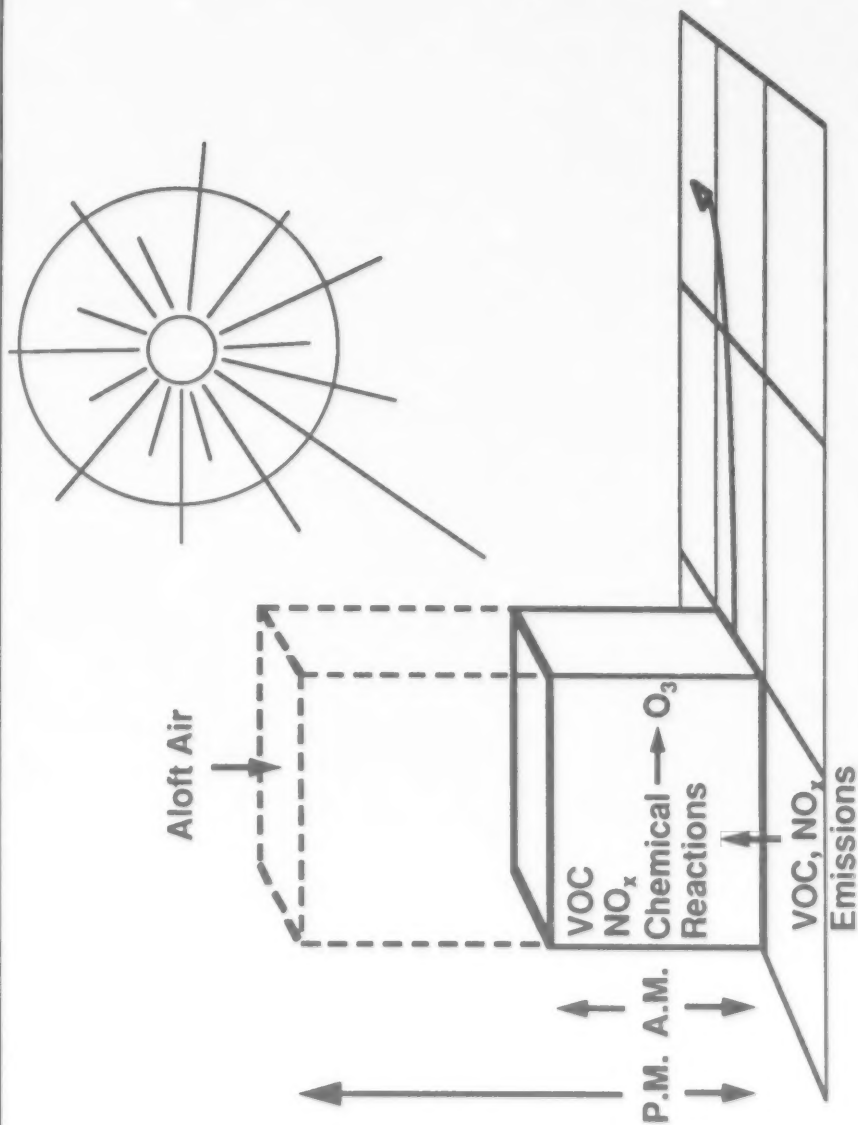
- University of California, Riverside*

- Implementation of Atmospheric Chemical Mechanism
 - Experiments on Methyl T-Butyl Ether (MTBE)

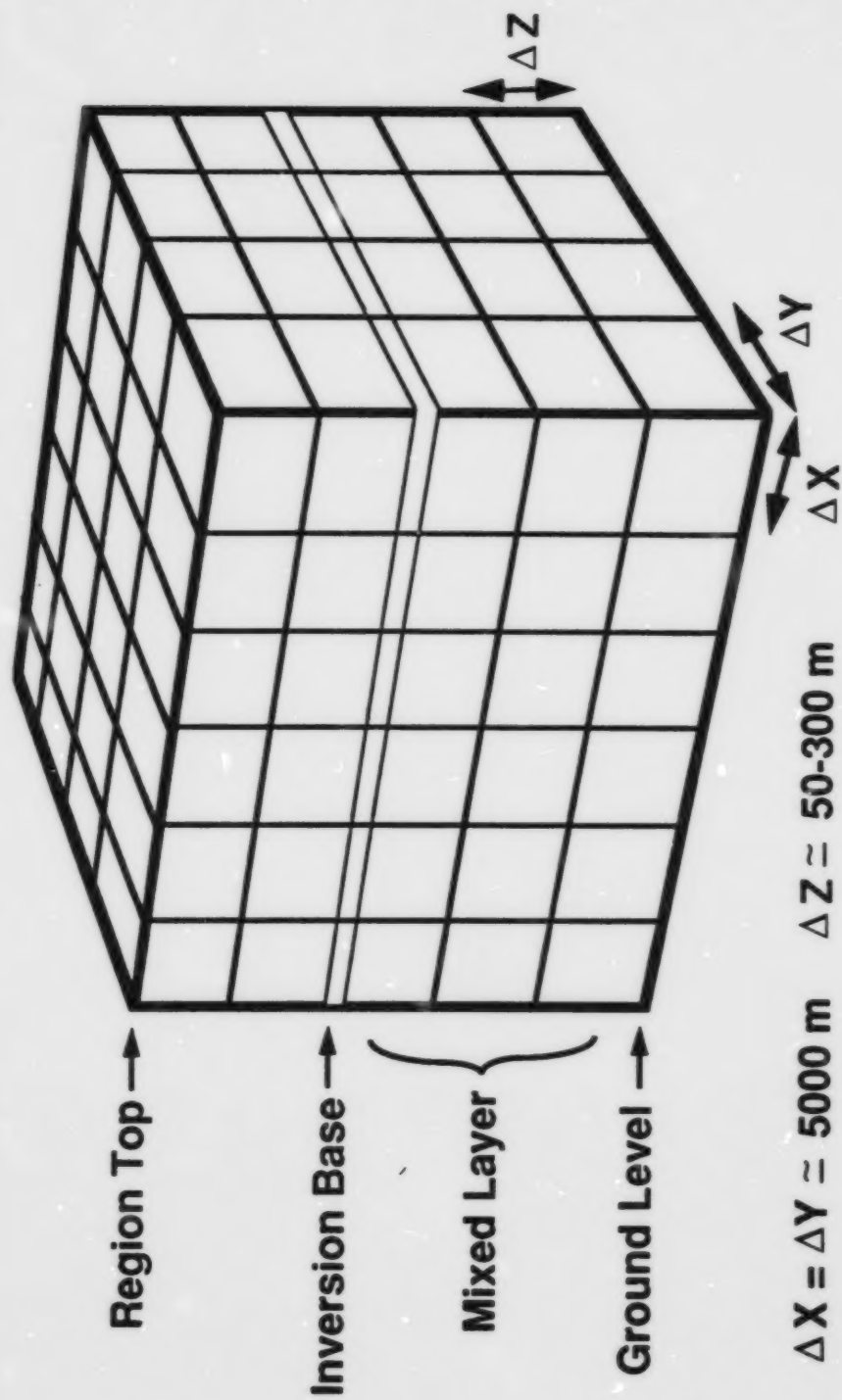
OVERVIEW OF THE MODELING APPROACH

- Screening Assessment
 - A Simple Trajectory Model Will Be Run for Scenarios Corresponding to All Fuels Tested
- Final Assessment
 - A Detailed, Three-Dimensional Grid Model Will Be Run for Those Scenarios That, According to the Trajectory Model, are Most Beneficial in Reducing Ozone
- Both Assessments Will Be Done for the Same Ozone Episodes

OZIPM4 MODEL



URBAN AIRSHED MODEL



CITIES SELECTED

- Los Angeles
 - Ozone Episode of June 5-7, 1985
- Dallas/Fort Worth
 - Ozone Episode of August 29-31, 1985
- New York Metropolitan Area
 - Ozone Episode of July 21-22, 1980

FUTURE YEARS SELECTED

- **Short-Term Year**

- **Year 1995 for All Cities**
- **Use Data from Older (1983-1985) and Current Vehicles (1989) to Develop Emissions Inventories**

- **Long-Term Year**

- **Year 2005 for Non-California Cities**
- **Year 2010 for Los Angeles**
- **Use Only Data from Current Vehicles to Develop Emissions Inventories**

ECONOMICS COMMITTEE OBJECTIVES

• Phase I

- Develop Cost Estimates to Determine the Relative Cost-Effectiveness of Various Fuel Alternatives for Reducing Ozone-Causing Emissions
- Alternatives to be Evaluated Include:
 - Reformulated Gasolines that may (or may not) Require Refinery Modifications
 - Flexible Fuel Vehicles Operating on M-85, Including Vehicle Modification Costs and Delivered Fuel Costs

• Phase II

- Provide Necessary Economic Support to Phase II Program in a Timely Fashion as Developed Through the Research Program Committee

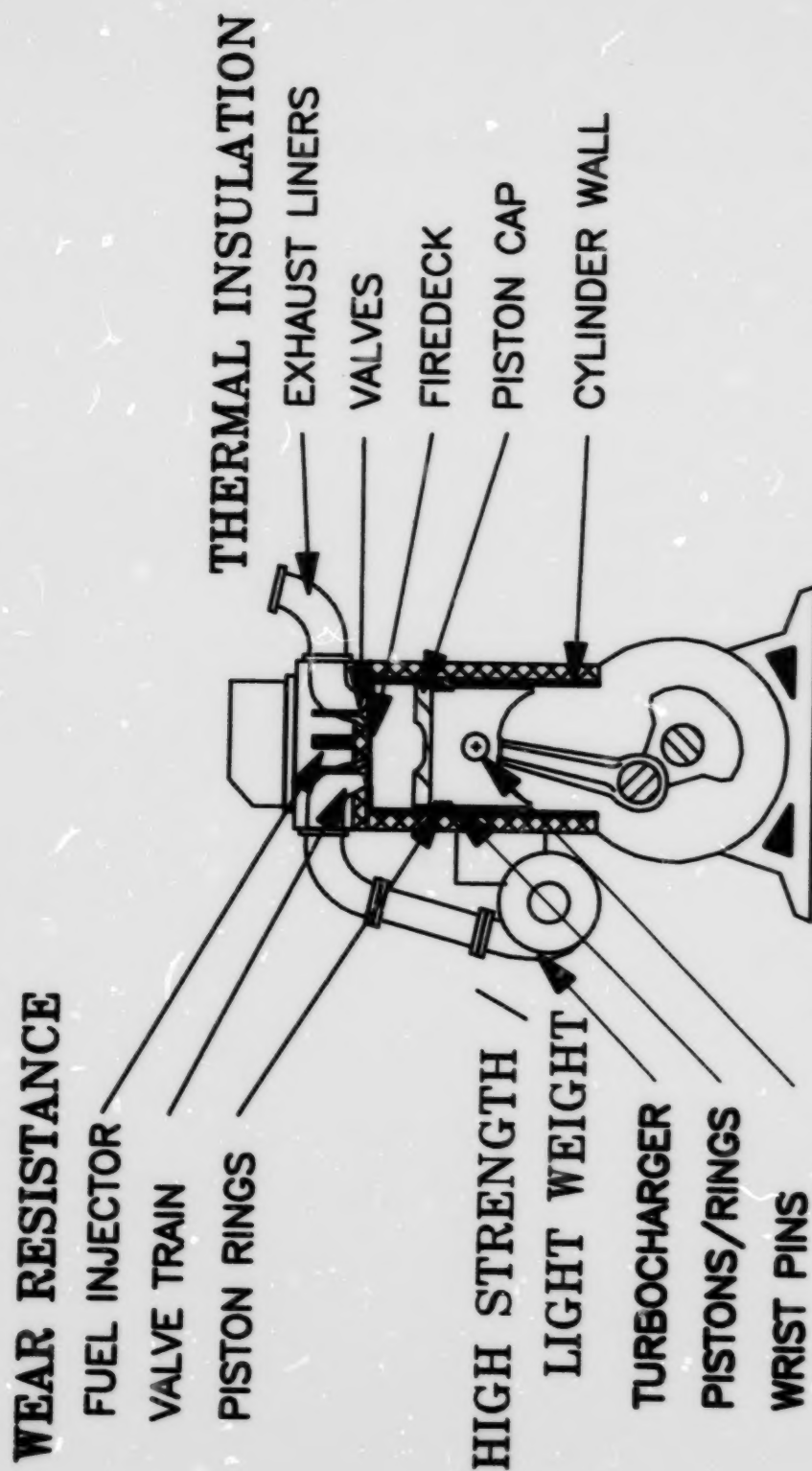
FUEL AND LUBRICANT EFFECTS
IN LOW HEAT REJECTION
DIESEL ENGINES

A.G. BLAHEY
K.F. LAYCOCK
RESEARCH DEPARTMENT
ESSO PETROLEUM CANADA

RESEARCH PROGRAM

- DETERMINE LUBRICATION REQUIREMENTS OF ADVANCED CERAMICS
- DEVELOP HIGH TEMPERATURE LUBRICANTS FOR LOW HEAT REJECTION (LHR) ENGINES
- ASSESS FUEL REQUIREMENTS FOR LHR OPERATION
- ESTABLISH ENERGY CONSERVATION/EMISSIONS

CERAMIC APPLICATIONS



LOW HEAT REJECTION ENGINES

- LOW HEAT REJECTION (LHR) ENGINES TRANSFORM WASTE HEAT INTO USEFUL WORK
- PARTIAL LHR POSSIBLE WITH CONVENTIONAL ENGINES, BUT METALLURGY IS A LIMITING FACTOR
- TRUE LHR DESIGNS MADE POSSIBLE THROUGH USE OF ADVANCED CERAMICS

POTENTIAL BENEFITS FROM

LHR ENGINES

- LOWER PARTICULATE EMISSIONS
- IMPROVED FUEL FLEXIBILITY
- INCREASED FUEL ECONOMY

2-STEP APPROACH TO LHR

MODERATE LHR

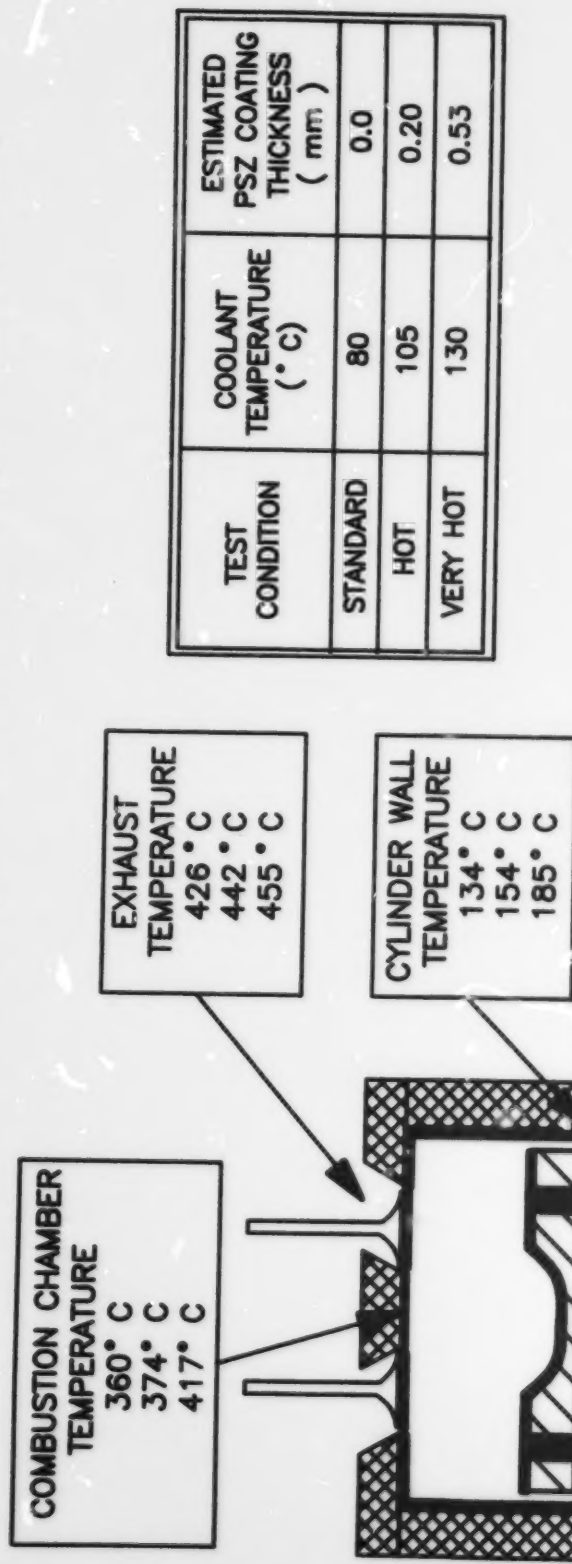
- METAL COMPONENTS
- 50C ABOVE CONVENTIONAL TEMPERATURES

SEVERE LHR

- CERAMIC COMPONENTS
- ANTICIPATE 100C ABOVE CONVENTIONAL TEMPERATURES

IMPACT OF LOW HEAT REJECTION ON ENGINE TEMPERATURES / LUBRICANT ENVIRONMENT

(METAL ENGINE COMPONENTS, 2000 rpm, 15 psi BOOST, 40 kW)



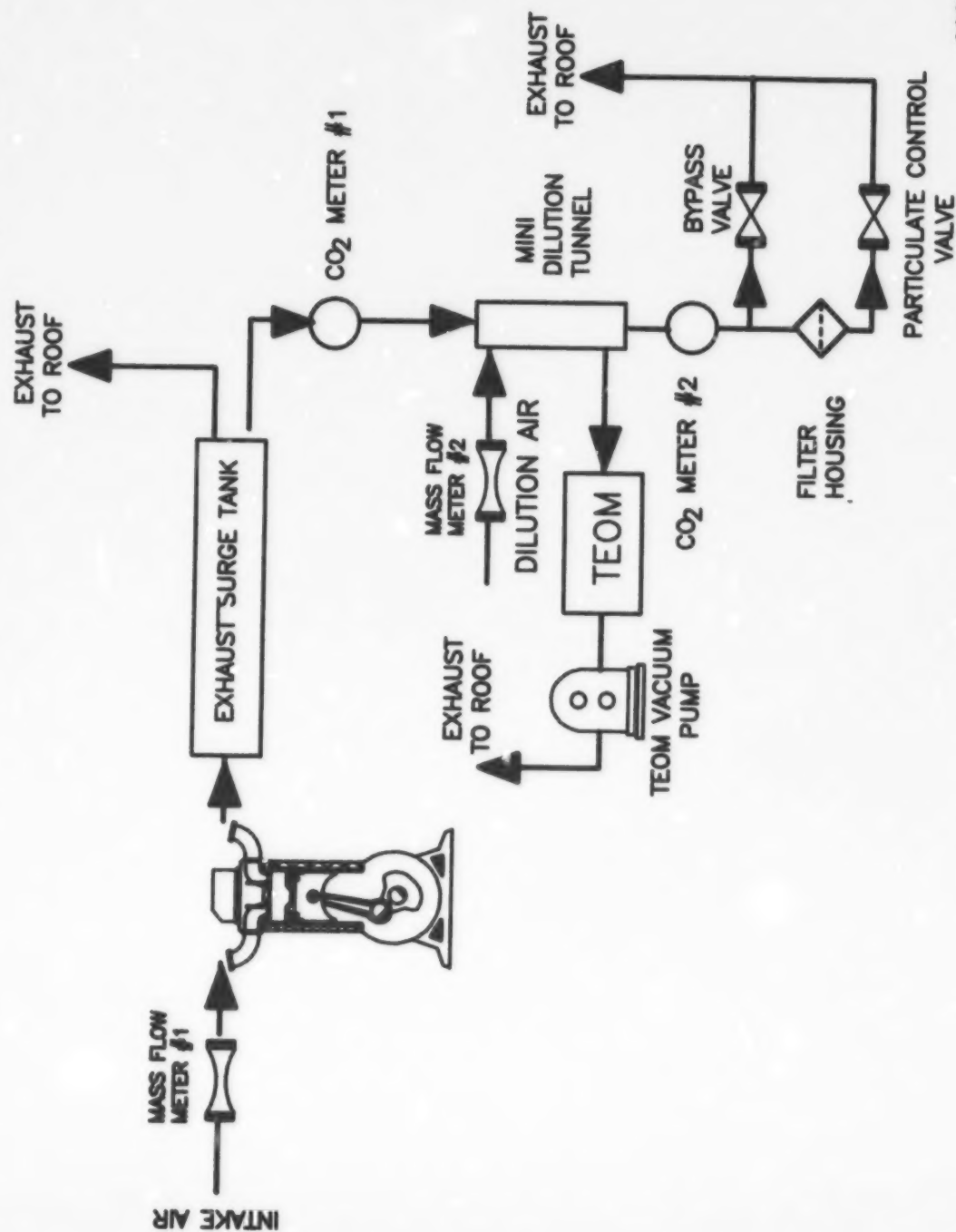
METAL COMPONENTS / CUT-BACK COOLING
EFFECTIVELY SIMULATE CERAMIC COATING
THERMAL EFFECTS & LOW HEAT REJECTION
CONDITIONS

CATERPILLAR 1Y540 CYLINDER

EXHAUST EMISSION MEASUREMENTS

- SEVERAL EXHAUST EMISSIONS FROM DIESEL ENGINE
 - GASEOUS: NOX, CO, CO₂, O₂, UHC
 - PARTICULATE
- GASEOUS EMISSIONS EASILY MEASURED WITH COMMERCIALY AVAILABLE EQUIPMENT
 - SAMPLE STRAIGHT FROM EXHAUST STREAM INTO ANALYSER FOR DIRECT RESULTS
- PARTICULATE EMISSIONS DIFFICULT TO MEASURE QUANTITATIVELY.....NEED
 - COOL AIR DILUTION TO QUENCH HOT EXHAUST AND FORM THE PARTICULATES
 - ACCURATE WEIGHTS OF VERY SMALL SAMPLES OF PARTICULATE

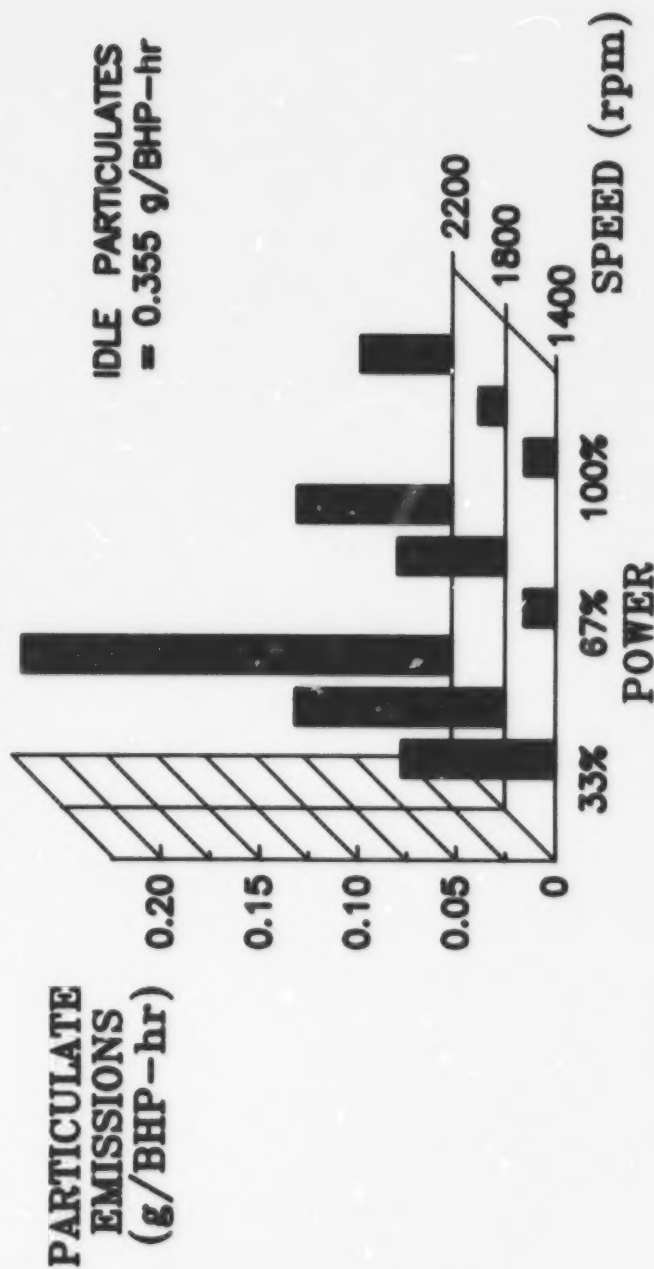
TEOM-BASED PARTICULATE MEASUREMENT SYSTEM



900322-18

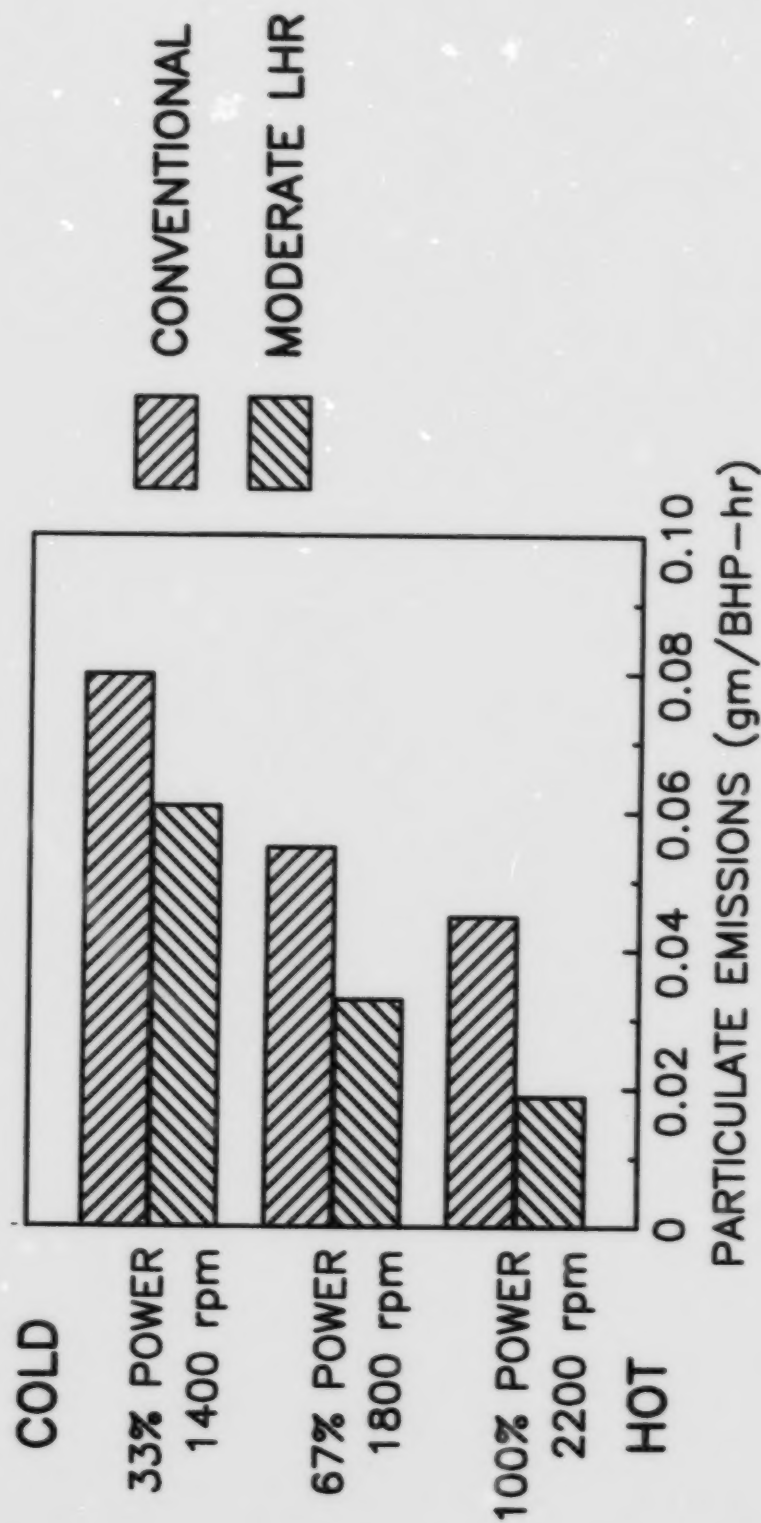
PARTICULATE EMISSIONS

STANDARD #2 DIESEL

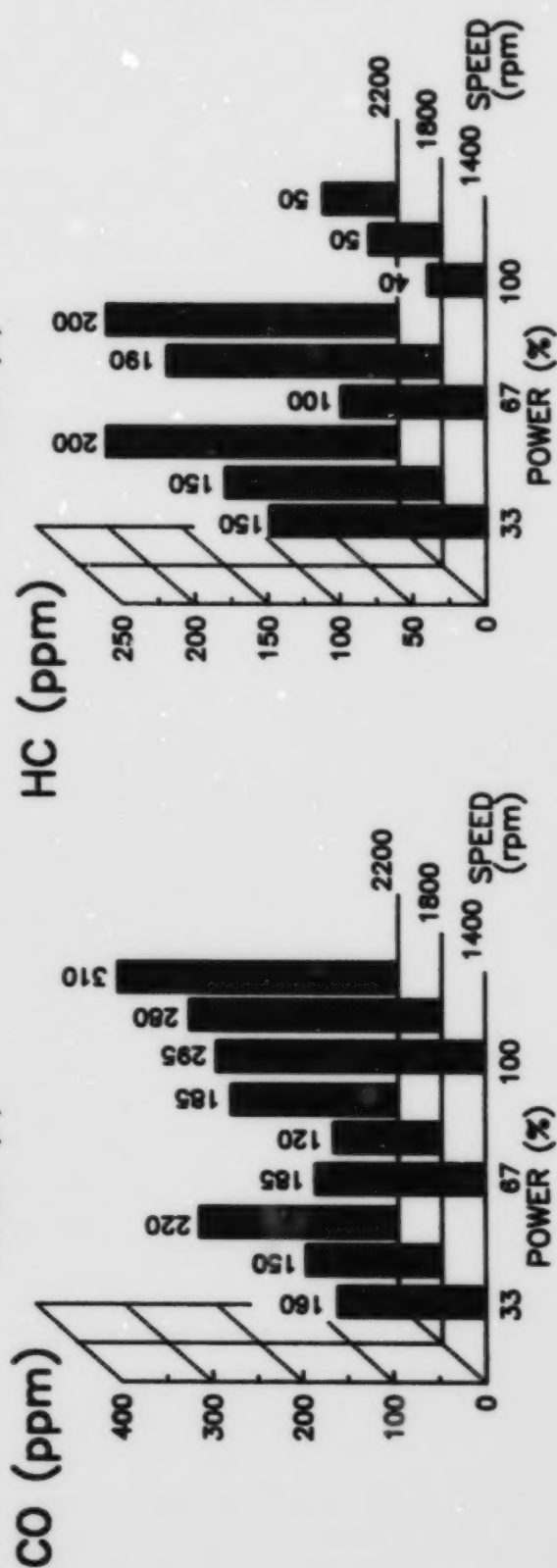
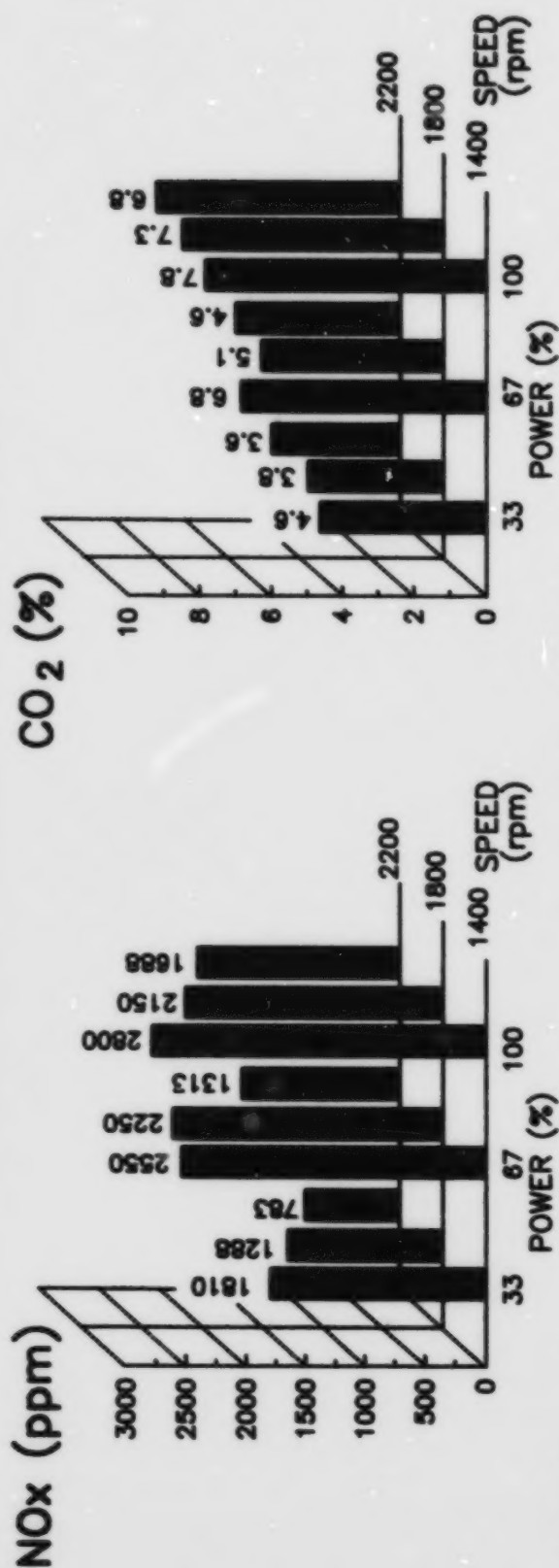


- PARTICULATE EMISSIONS QUANTIFIED FOR STEADY-STATE CONDITIONS WITH STANDARD #2 DIESEL FUEL
- EMISSIONS DECREASE WITH INCREASING POWER / DECREASING SPEED
 - HIGHER OPERATING TEMPERATURES REDUCE PARTICULATES
- EPA EMISSION CYCLE PROBABLY GENERATES HIGHER EMISSION LEVELS DUE TO TRANSIENT / LOW SPEED OPERATION
 - 1991/94 LEGISLATION IS 0.25/0.10 g/BHP-hr

EFFECT OF LOW HEAT REJECTION ON PARTICULATE EMISSIONS

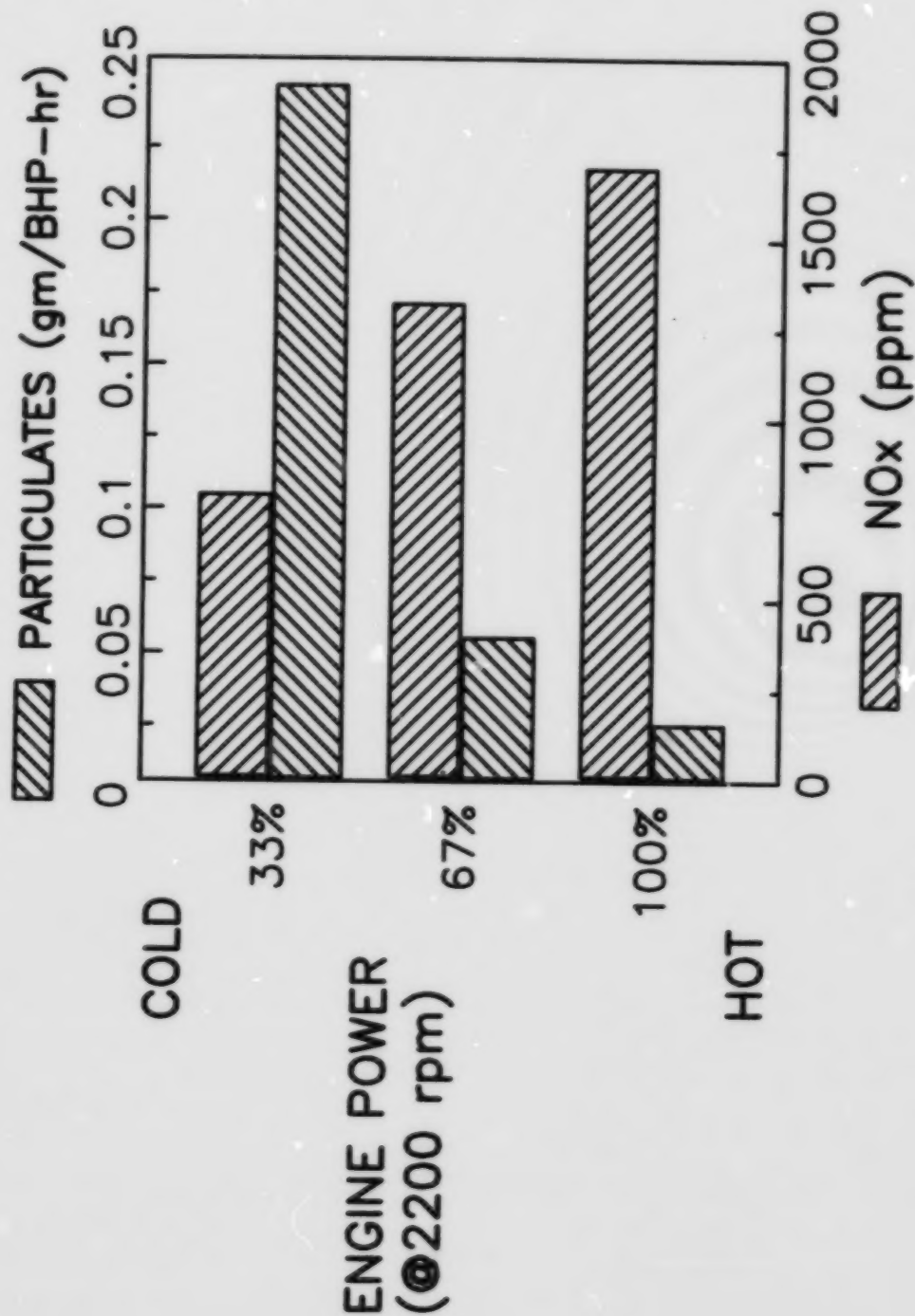


GASEOUS EMISSION MAPS



PARTICULATE AND NO_x EMISSION

TRADE-OFF



SUMMARY

- LHR OPERATION/BENEFITS REVIEWED
- LHR ENGINE TEST DEVELOPED
 - OPERATING TEMPERATURES ESTABLISHED
- PARTICULATE/GASEOUS EMISSION MEASUREMENT CAPABILITY DEVELOPED
- EMISSIONS SHOW EFFECT OF
 - ENGINE SPEED, LOAD
 - LHR OPERATION
 - PARTICULATES/NO_x TRADE-OFF

FUTURE WORK

- CONTINUE HIGH TEMPERATURE LUBRICANT DEVELOPMENT
- CONFIRM DURABILITY OF ENGINE WITH LATEST LUBRICANT FORMULATIONS
- CONDUCT EXTREME LHR ENGINE TESTING WITH CERAMIC COMPONENTS
- ESTABLISH INFLUENCE OF VARIOUS FUELS ON ENGINE DEPOSITS/EMISSIONS

**SESSION 1 - LIGHT/MEDIUM DUTY VEHICLES
C - METHANOL**

**Co-Chairs: R. Neville, ORTECH International
R. McGill, Oak Ridge National Laboratory**

TAILPIPE EMISSIONS FROM GM VARIABLE-FUEL CORSICAS
Frank Ament - GM/Advanced Engineering Staff

SLIDE 2

In reviewing the tailpipe emissions data from the Variable-Fuel Corsicas, I will cover the following topics: Vehicle/System description, low-mileage emissions from 20 California Corsicas, mixed-mileage emissions from 6 Auto/Oil Fleet Corsicas, and the 33,000 mile emissions history of a California Corsica. I will conclude by summarizing our tailpipe emissions experience.

SLIDE 3

The Corsica Variable-Fuel System includes a stainless-steel fuel tank, methanol-tolerant, high-flow fuel pump and injectors. The Capacitive fuel sensor is mounted underhood, close to the fuel injector rail to reduce the fuel transport delay. The engine control software and calibration has been developed to handle the broad range of fuel blends under all operating conditions.

SLIDE 4

The GM Capacitive fuel sensor is the key component of the Variable-Fuel control system. It measures the dielectric properties of the alcohol-gasoline blends and allows the on-board computer to automatically compensate the fuel quantity based on the energy content of the fuel blend.

SLIDE 5

Since the Variable-Fuel system must meet the emission standards with gasoline, as well as with M85, the production underfloor catalytic converter was retained. The 170 cuin, Platinum/Rhodium monolith is located under the front seat floor pan.

Catalyst durability and conversion deterioration was expected to be comparable to the gasoline systems. However, catalyst warm-up was slower with M85, due to lower engine exhaust temperatures.

SLIDE 6

For low tailpipe emissions, accurate fuel control must be maintained under all vehicle operating conditions. To simultaneously reduce unburned fuel, carbon monoxide, and nitrogen oxides, the three-way catalyst requires fuel control within plus or minus 0.2% of stoichiometry

This slide compares the gasoline and M85 air-fuel ratio histograms during a Federal Emissions test. With M85, the exhaust air-fuel ratio entering the catalytic converter is less optimum for simultaneous oxidation and reduction of the engine-out emissions.

Even with software compensation, transient fuel control with high levels of methanol is not as accurate as with gasoline. This is due to the large amount of liquid fuel required and the high latent heat of vaporization of the methanol.

SLIDE 7

Using the gasoline production emission control hardware, the Variable-Fuel Corsica meets the current Federal and California tailpipe emissions standards at low mileage. The level of Organic Material HC Equivalent, CO and NOx emissions remains relatively constant with fuel blends ranging from 100% gasoline, up to 85% methanol.

However, the formaldehyde emissions increase from 4 mg/mile with gasoline, to 25 mg/mile with M85. Most of the tailpipe formaldehyde emissions occur during the cold portion of the Federal Test Procedure, before the catalytic converter is fully active. For reference, the formaldehyde emissions jump to 35 mg/mile with M100.

Although faster converter warm-up reduces formaldehyde emissions, compliance with the 15 mg/mile standard at 50,000 miles would still be questionable.

SLIDE 8

Because methanol contains one-half the energy per gallon compared to gasoline, the fuel economy decreases as the methanol content increases. With M85, the fuel economy and driving range is 39% lower than with gasoline.

As shown in parenthesis, the efficiency on an equivalent Btu basis actually increases with higher methanol levels. For the same energy input, the M85 fuel is actually 7% more efficient than gasoline. The gain results primarily from methanol's higher flame speed and lower combustion temperatures.

A similar increase in torque and peak power is also observed.

SLIDE 9

In April 1989, 20 Variable-Fuel Corsicas were delivered to the California Energy Commission to participate in their Methanol Demonstration Fleet. The vehicles were split between the Sacramento and the Los Angeles area fleets.

SLIDE 10

The Corsicas were tailored to meet the tailpipe and evaporative emission limits set forth by the California Air Resources Board for methanol-fueled vehicles. Organic Material HC Equivalent includes the non-oxygenated HC emissions measured by Flame Ionization Detection, plus the non-oxygen mass of the methanol and formaldehyde emissions measured by gas and liquid chromatography.

The 20 Variable-Fuel Corsicas, and the subsequent 2200 Lumina that will be delivered to California beginning in December of 1990, will be operating under a special permit allowing higher formaldehyde emissions.

SLIDE 11

These are the low-mileage emission results from the 20 California Corsicas. Due to the low mileage of approximately 1000 miles, the emissions are quite good. There is little difference between the gasoline and M85 emissions, with the exception of formaldehyde. The average level of 19 mg/mi with M85 fuel, is 6 times higher than the average with gasoline.

As discussed previously, the equivalent energy fuel economy was 4-7% higher with M85.

SLIDE 12

This slide shows the distribution of the formaldehyde test data from the 20 Corsicas. Each vehicle was tested twice with gasoline and M85. Even at 1000 miles, the mean M85 formaldehyde level of 19 mg/mi is well above the 15 mg/mi standard. The 2 test average for each vehicle actually ranged from 14 to 23 mg/mi.

The mean gasoline formaldehyde level was only 3 mg/mi, and the 2 test average for each vehicle ranged from 2 to 8 mg/mi.

SLIDE 13

Six Variable-Fuel Corsicas are also participating in the Auto/Oil Industry Air Quality Research Program. These vehicles were pulled from engineering, durability and oil company-designated fleets. The fuel system and emissions control hardware is identical to the California Corsica fleet, and the older vehicles were updated to the same calibration level.

SLIDE 14

The following slides show the FTP emission test results for the six Auto/Oil Fleet Corsicas. Again each vehicle was tested twice with gasoline and M85.

As shown here, the HC equivalent emissions are similar and well within the standard.

SLIDE 15

The CO emissions with gasoline and M85 are also similar and well within the 7.0 gm/mi standard.

SLIDE 16

As expected, the NOx emissions with gasoline and M85 are also similar. These slides also provide the opportunity to make an important point.

It would be natural to assume that the highest emissions data with both gasoline and M85 came from the same vehicle. This is not usually the case with variable-fueled vehicles, because the gasoline and methanol calibrations are essentially independent.

SLIDE 17

This slide shows the average tailpipe formaldehyde emissions versus mileage. With M85, the four 10,000 mile Corsicas averaged 22 mg/mi, while the 33,000 mile Corsica averaged nearly 30 mg/mi.

The gasoline formaldehyde emissions ranged from 4-5 mg/mi at 10,000 miles, and increased to 6 mg/mi for the 21,000 and 33,000 mile vehicles.

Despite the small sample size and the varied operating history of these vehicles, the formaldehyde levels are representative of the cumulative durability and engineering development experience with the Variable-Fuel Corsica.

SLIDE 18

The 33,000 mile vehicle in the Auto/Oil Research fleet was the first Variable-Fuel Corsica that was delivered to the California Energy Commission in December 1987. This Corsica accumulated 33,000 miles during two years of California fleet service. Throughout this period, the tailpipe emissions, driving schedule, fuel use and service were documented.

SLIDE 19

The next two slides summarize the tailpipe emissions history of the 33,000 mile Corsica. During the California mileage accumulation, this vehicle was emissions tested at the Air Resources Board facility in El Monte and at the Chevron Research facility in Richmond.

With gasoline, the CO and NOx emissions are well controlled and comply with the California Standards.

With M85, the NOx emissions with the original calibration were higher than 0.4 gm/mi. When the vehicle was returned to AES in December of 1989, the M85 calibration was updated to the level of the California Corsicas. This reduced the NOx level, and increased the CO emissions slightly.

SLIDE 20

The HC equivalent emissions with M85 remained well below the 0.41 gm/mi standard throughout the mileage accumulation. With gasoline however, the HC exceeded the standard at 33,000 miles. This problem will be discussed later.

Of particular interest is the formaldehyde emissions history. It should be noted that no formaldehyde control work was done on this vehicle in August 1987, because tailpipe measurement facilities were not available.

The results from the A.R.B. and Chevron test facilities show that the formaldehyde emissions remained above 30 mg/mi from 4500 to 20,000 miles. The 33,000 mile data from the GM facility was slightly lower. These long-term results suggest that the formaldehyde emissions deterioration was relatively small compared to the high initial level.

It should be noted that the prototype methanol injectors used in this Corsica were replaced shortly before each emissions test sequence to insure proper fuel system performance.

Although the gasoline formaldehyde emissions were generally under 10 mg/mi, the individual test results varied by a large percentage and didn't appear to follow the M85 trend. The variability in both the gasoline and M85 formaldehyde data may be due to test facility differences and fuel control variability with the early variable fuel system components.

SLIDE 21

As previously stated, the increase in gasoline HC emissions was investigated. The low converter efficiencies at 33,000 miles suggested that prolonged methanol exposure may have reduced catalyst performance. The converter was removed and sent to the supplier for evaluation.

A 21,000 mile converter from a newer Variable-Fuel Corsica was installed and tested. While the tailpipe HC were slightly lower with this converter, the conversion efficiency during the stabilized portion of the emissions test procedure did not improve significantly. In the final step, the gasoline calibration was updated and the HC emissions and converter efficiencies returned to an acceptable level.

SLIDE 22

The 33,000 mile production catalytic converter was visually inspected and tested for exhaust emissions performance. Visual inspection of the monolith showed no signs of thermal or chemical damage. The canister also appeared typical, with only light rust corrosion.

An air-fuel ratio sweep test was run on an engine dynamometer. The simultaneous CO and NOx conversion efficiency of 95.4% was within acceptable limits.

Overall, the converter was judged typical of a gasoline vehicle with similar mileage.

It should be noted however, that mileage accumulation in the California fleet is relatively light-duty operation. A driving cycle which includes extended high-speed, high-load operation could have a more dramatic effect on the catalytic converter.

SLIDE 23

Over the past 2 1/2 years, the Variable-Fuel Corsicas have been emission tested at several government and private facilities throughout the United States. We can only estimate the correlation of these facilities with our own. To date, the only A-B comparison was run with the EPA-RTP facility and the formaldehyde results were within 15% for a 25 mg/mi vehicle.

In certifying future Variable-Fuel vehicles for the 15 mg/mi formaldehyde standard, measurement accuracy, repeatability and site-to-site correlation will be a major concern.

SLIDE 24

After 3 yrs of testing and development, the following observations can be made about the Variable-Fuel Corsicas tailpipe emissions:

VARIABLE - FUEL CORSICA LONG - TERM CALIFORNIA FLEET USE

2 YEARS (Dec 87 - Dec 89)

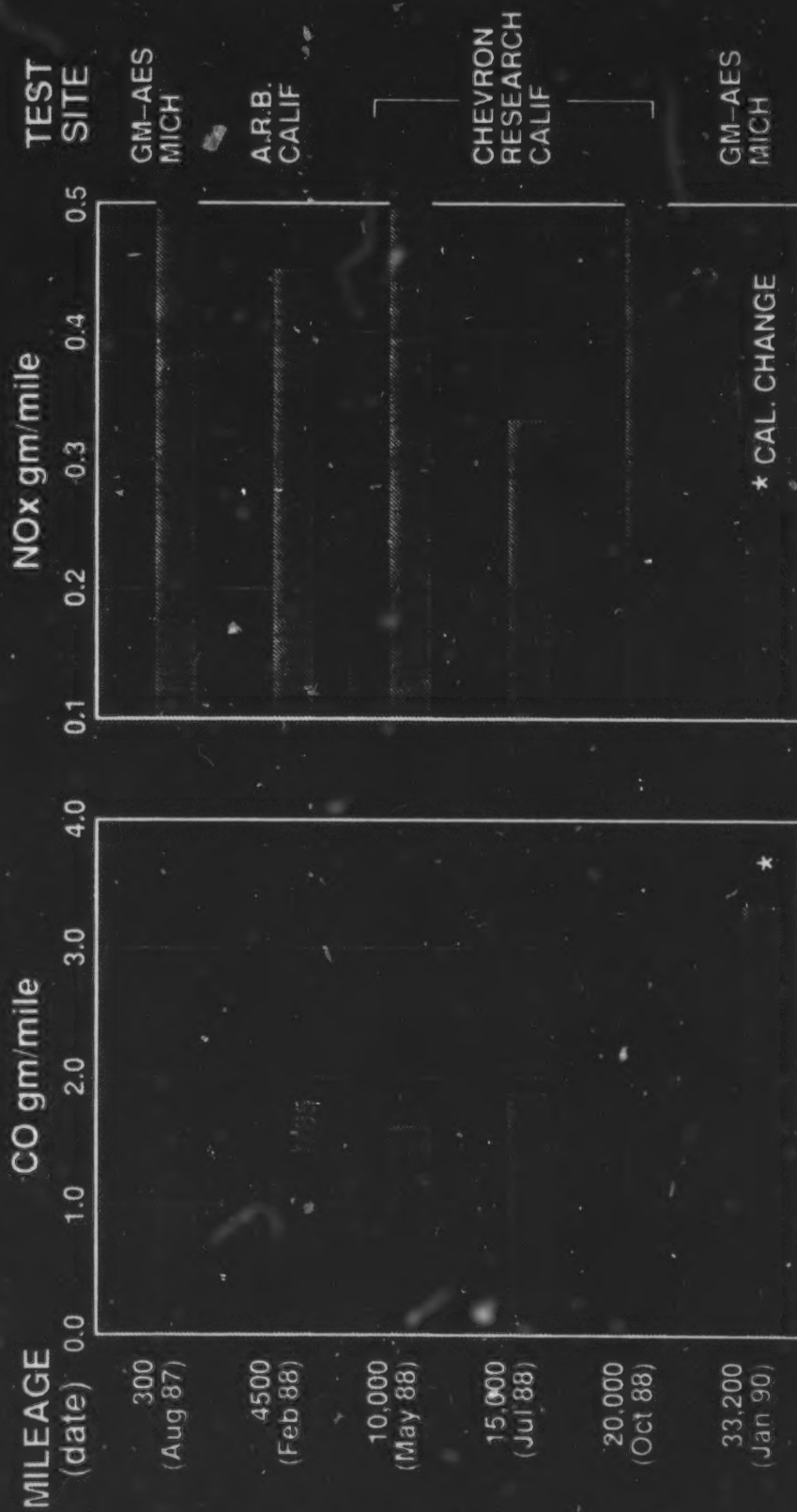
33,000 Miles

DOCUMENTATION

- Emissions
- Driving Schedule
- Fuel Blend
- Service

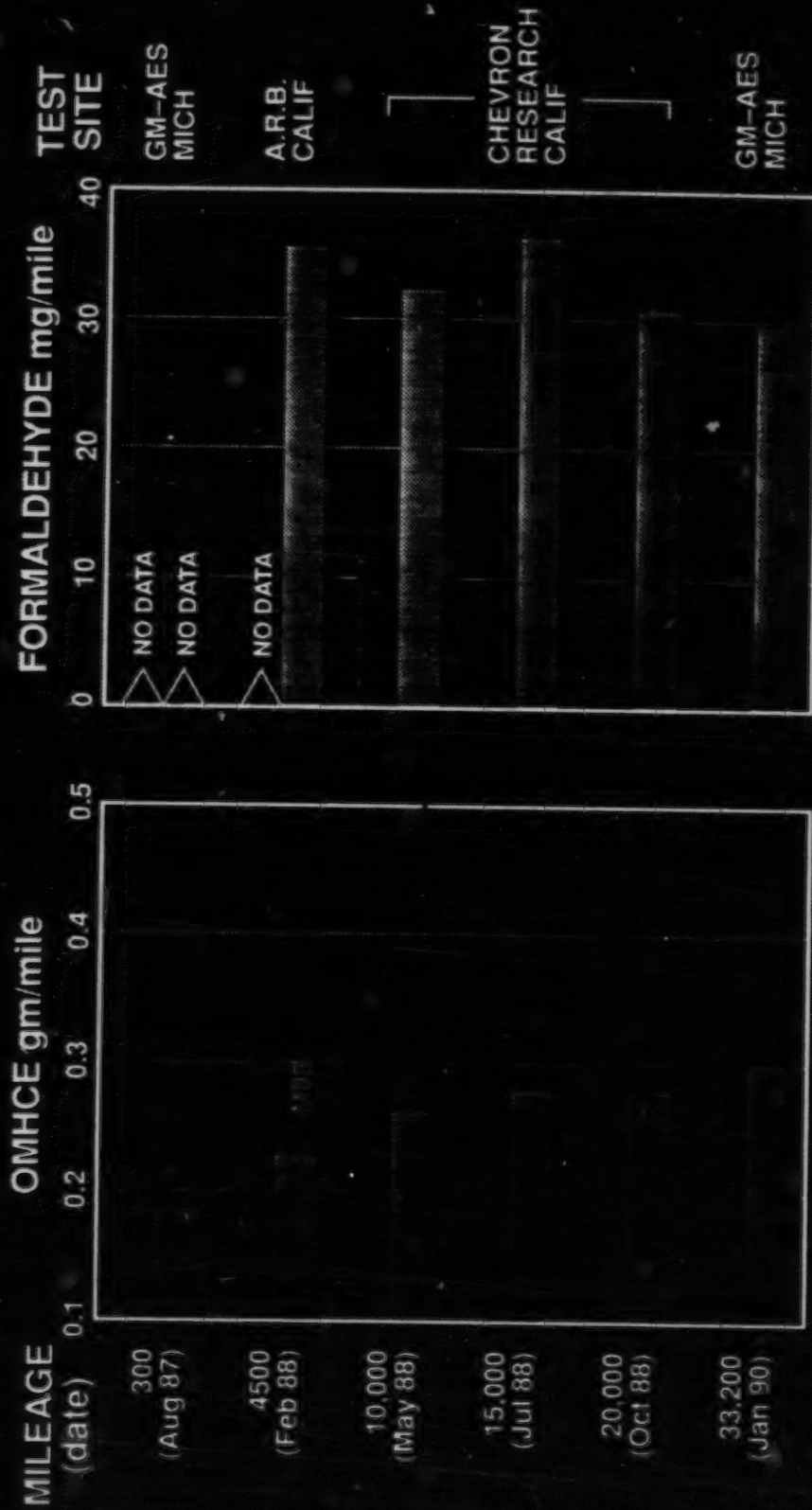
VFV Corsica Long-Term Emissions

1988 - 2.8L V6, MPFI, Prod Catalyst, Trans A3



V6 Corsica Long-Term Emissions

1988 - 2.8L V6, MPFI, Prod Catalyst, Trans A3



Variable-Fuel Corsica

Gasoline Emissions History

MILEAGE (SITE)	GM/MI		STABILIZED CONV %	
	HC	CO	HC	CO
300 (GM-AES)	0.19	1.00	99.1	99.0
4500 (C.A.R.B.)	0.22	1.64	—	—
33100 (GM-AES)	0.46	3.30	95.2	84.7
				84.6

INSTALLED 21,000 MILE CATALYTIC CONVERTER FROM ANOTHER VEHICLE

0.41	3.10	0.26	95.2	84.4	88.3
CALIBRATION CHANGE					
0.27	1.40	0.32	99.7	96.2	87.5

Variable-Fuel Corsica Catalyst Inspection

After 33,000 Miles – California Fleet Use

**1988 Prod. – 170 cu in, Dual-Brick Monolith
Three-way, Pt-Rh Catalyst**

- **Visual**

- Normal appearance
- No visible monolith melting
- Light corrosion

- **Air/Fuel Ratio Sweep Test**

- NOx/CO crossover efficiency – 95.4%

- **Conclusions**

- Acceptable converter appearance and performance
- Typical for mileage and operating conditions

Methanol Emissions Test Facilities

Variable-Fuel Corsica Experience

TEST SITE

A → B COMPARISON

**California Air Resources Board
El Monte, Calif.**

**No
< 20% est.**

**Chevron Research Company
Richmond, Calif.**

**No
< 20% est.**

**EPA – Research Triangle Park
North Carolina**

**Yes
< 15%**

**Southwest Research Institute
San Antonio, Tex.**

**No
< 20% est.**

**Ford Motor Company
Dearborn, Mich.**

(?)

Variable-Fuel Corsica Tailpipe Emissions

OBSERVATIONS

- The Variable-Fuel Corsicas meet the current California HC, CO and NOx emission standards on any gasoline/methanol blend from M0 to M85.
- Tailpipe formaldehyde emissions increase 4 to 6-fold as the alcohol content is increased from M0 to M85. Most of the formaldehyde emissions occur during the cold start before the catalyst is fully active.
- On average, the Variable-Fuel Corsicas tested exceed the 15 mg/mi formaldehyde standard by:
 - 25% at 1,000 miles, 50% at 10,000 miles, 100% at 50,000 miles
- Formaldehyde emissions could be higher if the fuel and control system deterioration is significantly worse than a production gasoline vehicle.
- One Corsica accumulated 33,000 miles in 2 years of California fleet use. Performance of the production catalyst was found to be acceptable.
- Methanol test facility correlation is very limited. Formaldehyde measurement accuracy needs verification.

TAILPIPE EMISSIONS FROM GM VARIABLE - FUEL CORSCICAS

Frank Ament

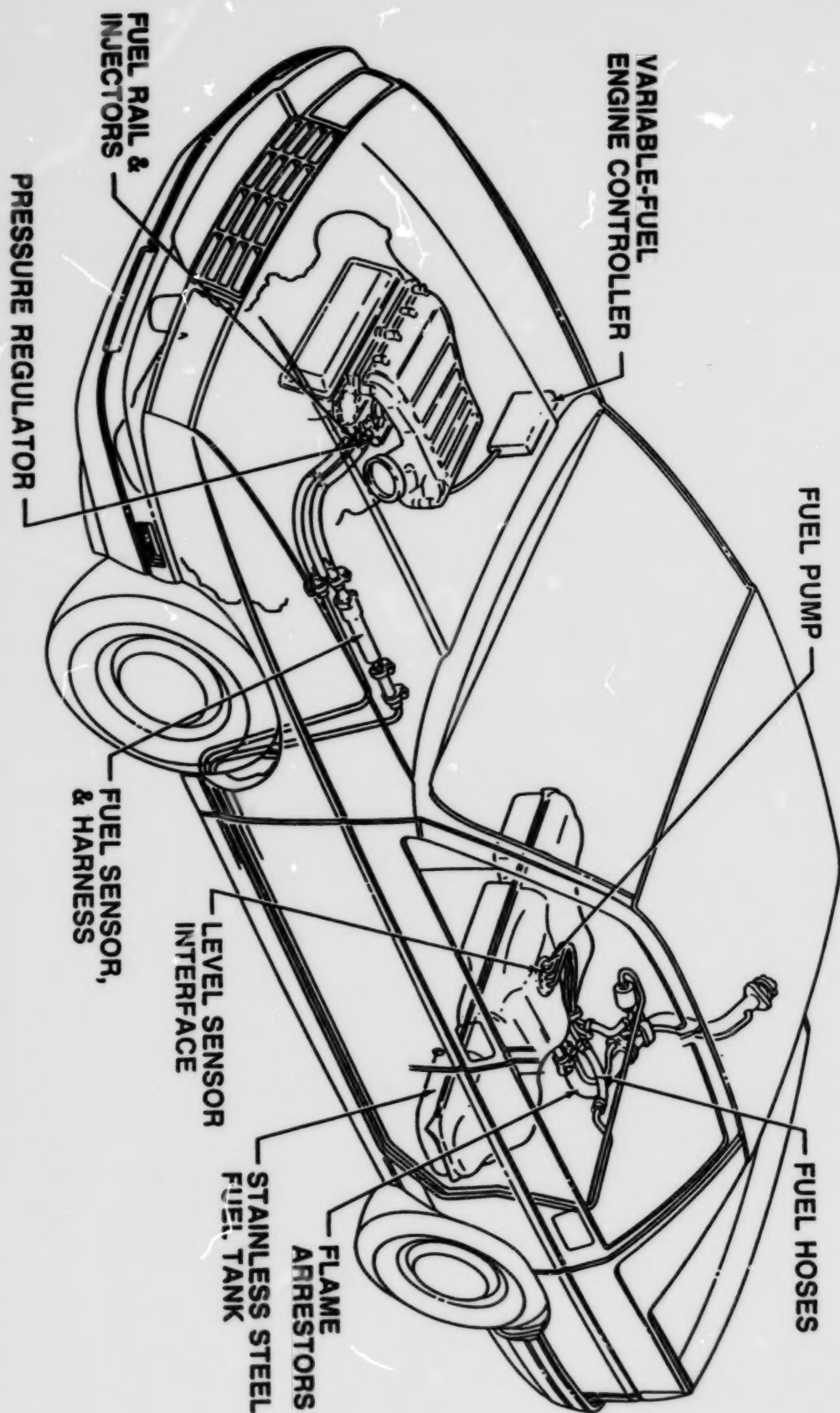
Advanced Engineering Staff

General Motors Corp.

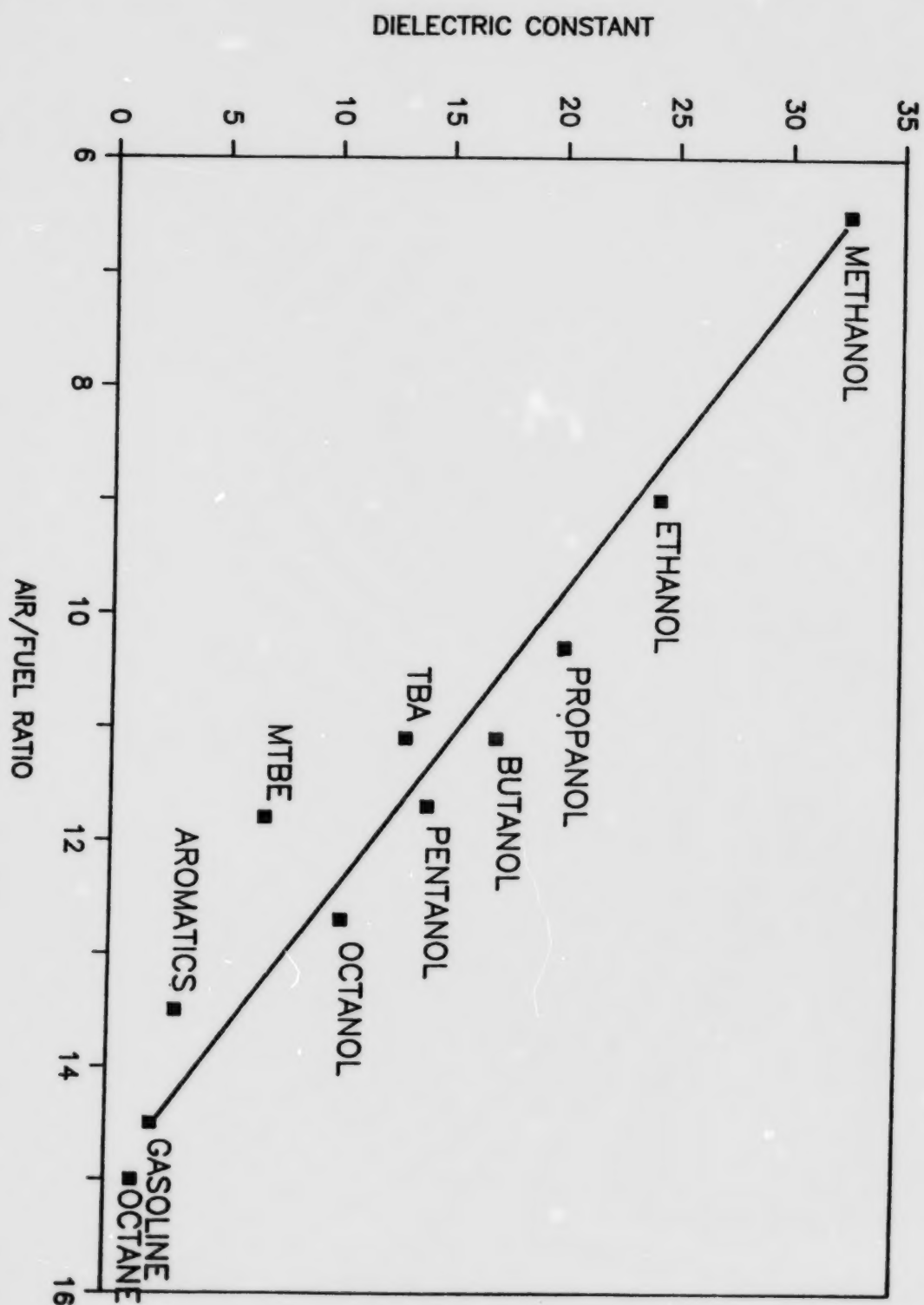
TAILPIPE EMISSIONS FROM GM VARIABLE - FUEL CORSICAS

- **Vehicle/System Description**
- **Low-Mileage Emissions From 20 Corsicas
in California Demonstration Fleet**
- **Emissions From 6 Corsicas in Auto / Oil
Research Test Fleet**
- **Emissions History of Long - Term California
Fleet Corsica**
- **Methanol Emissions Test Site Correlation**
- **Observations**

CALIFORNIA VARIABLE FUEL CORSICA
1988 2.8L V6, AUTO TRANS
SDF MPFI, MASS AIR FUEL CONTROL



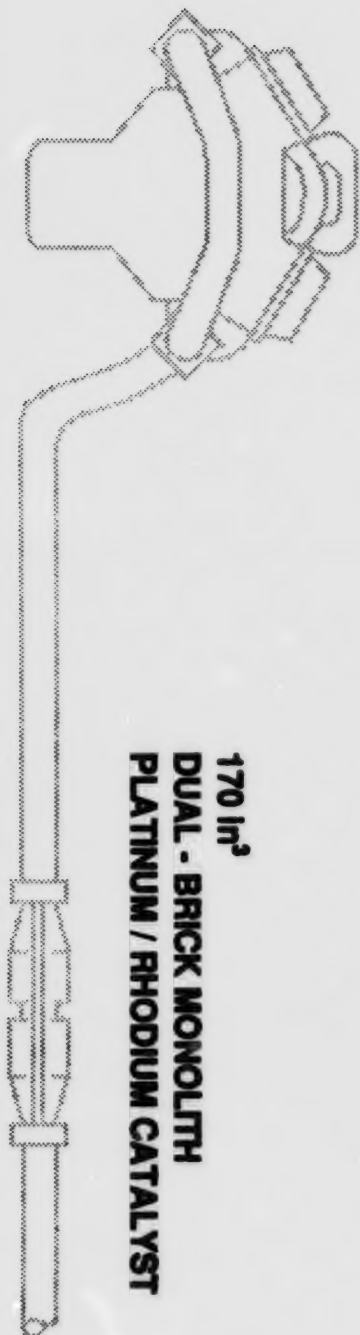
CAPACITIVE EFFECT



Variable-Fuel Corsica

1988 Production Catalyst System

**2.8L V6
PORT FUEL INJECTION**



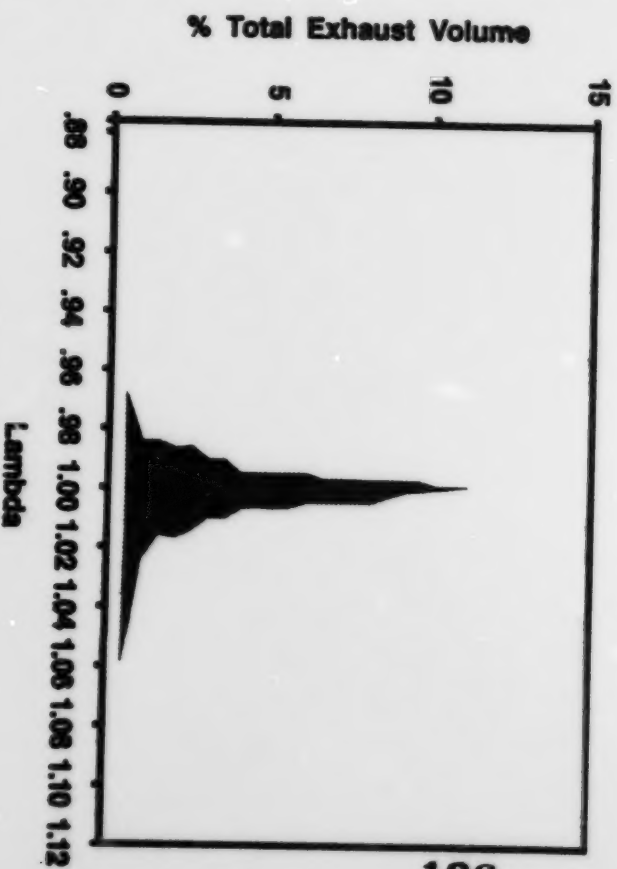
REAR EXHAUST MANIFOLD OUTLET TO CONVERTER INLET..... 34 INCHES
FRONT EXHAUST MANIFOLD OUTLET TO CONVERTER INLET..... 48 INCHES

Slide:2957-07

OpId:GM TECH CENTER

mK Job#:1177 A DDS:0510 Size:2822 Sun Apr 30 16:41:40 1989

GASOLINE vs. M85 A/F CONTROL



VARIABLE FUEL

1988 Corsica With Production Catalyst

4,700 Mile Data

'75 FTP Emissions
grams/mile

	<u>Fuel</u>	<u>OMHCE*</u>	<u>CO</u>	<u>NOx</u>	<u>HCOH</u>	<u>NOx</u>	HWY
	MO	0.28	2.3	0.2	0.004	0.15	
	M25	0.28	2.7	0.2	0.006	0.10	
	M50	0.22	2.0	0.2	0.012	0.20	
	M85	0.26	2.4	0.2	0.025	0.15	
Standards: Federal	0.41	3.4	1.0	---	---		
California	0.41	7.0	0.4	0.015	0.53		

* Reported Per EPA Procedure

VARIABLE FUEL

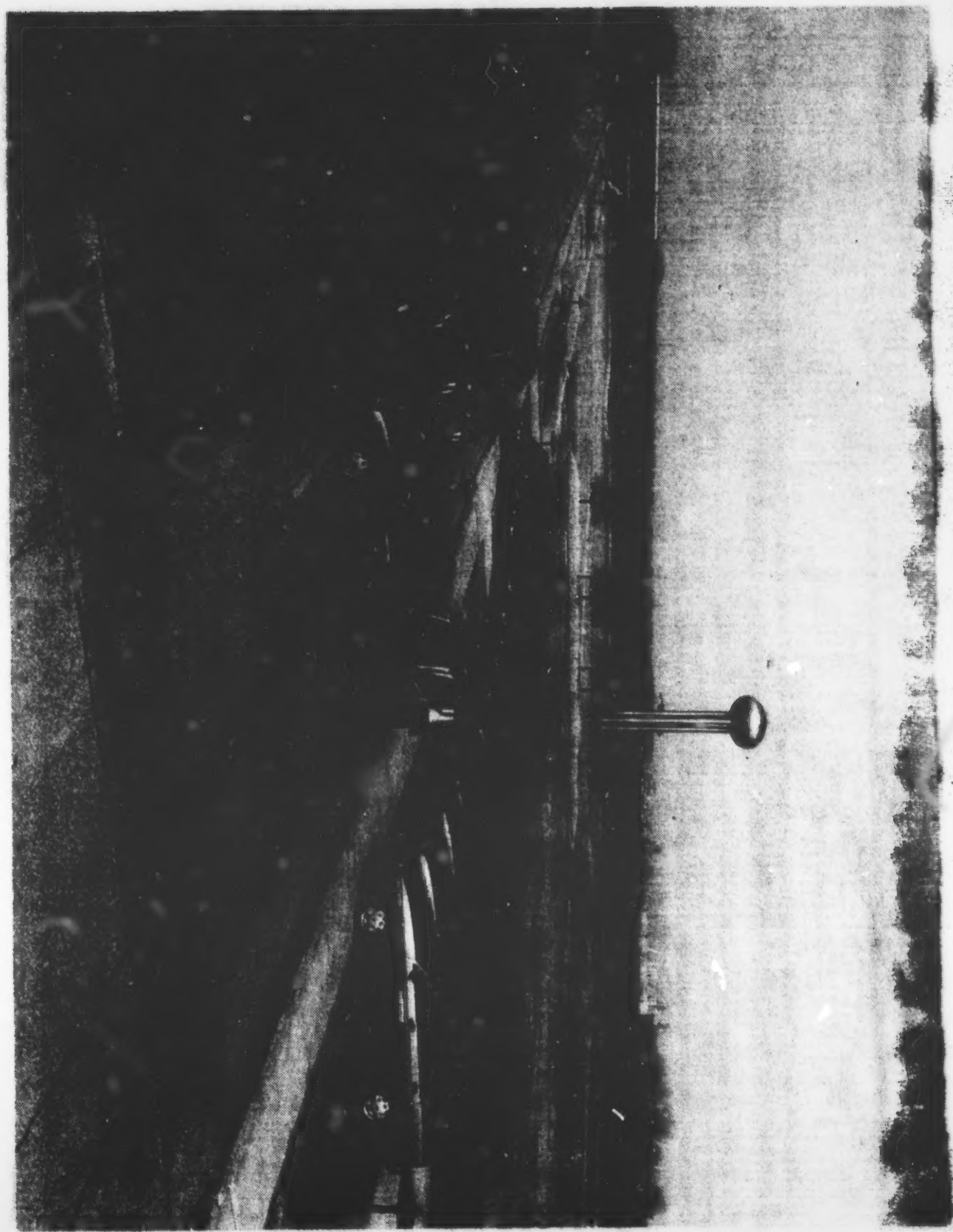
1988 Corsica With Production Catalyst

4,700 Mile Data

Fuel Economy
miles/gal

	<u>City</u>	<u>Highway</u>	<u>Combined</u>
MO	21.1	32.1	25.0
M25	18.8 (21.5)	28.8 (33.0)	22.2 (25.5)
M50	16.6 (22.2)	25.1 (33.6)	19.5 (26.2)
M85	12.9 (22.8)	19.5 (34.4)	15.2 (26.8)

(Gasoline Equivalent Basis)



CALIFORNIA EMISSION Standards For VFV Vehicles

Constituent	<u>g/mi</u>
OMHCE	0.41
CO	7.0
NOx	0.4
Highway NOx	0.53
EVAP	2.0 gm/test
Formaldehydes	0.015

Variable-Fuel Corsicas Low Mileage FTP Emissions

20 Car California Fleet
(average odometer 1,000 miles)

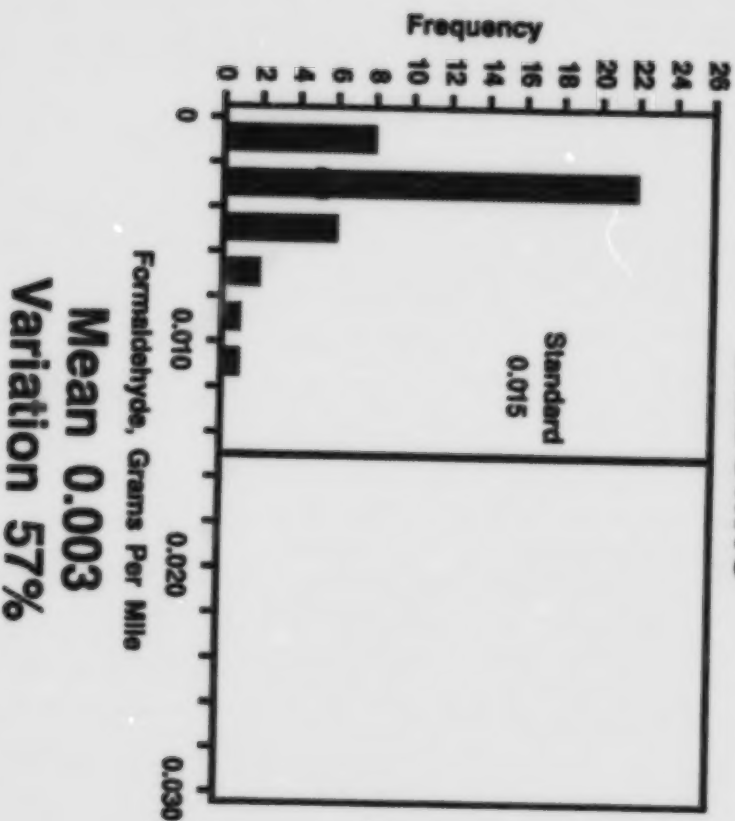
FUEL	gm/ml				mpg		gm/ml HWY NOx
	OMHCE	CO	NOx	HCOH	CITY	HWY	
GASOLINE	0.25 (16%)	1.68 (27%)	0.13 (35%)	.003 (57%)	20.0	31.3	0.14 (115%)
	0.20 (13%)	1.80 (27%)	0.15 (30%)	.019 (19%)	12.2	18.5	0.06 (60%)
M85					21.5 GASOLINE EQUIVALENT	32.6	

() INDICATES STANDARD DEVIATION AS A PERCENT OF THE AVERAGE

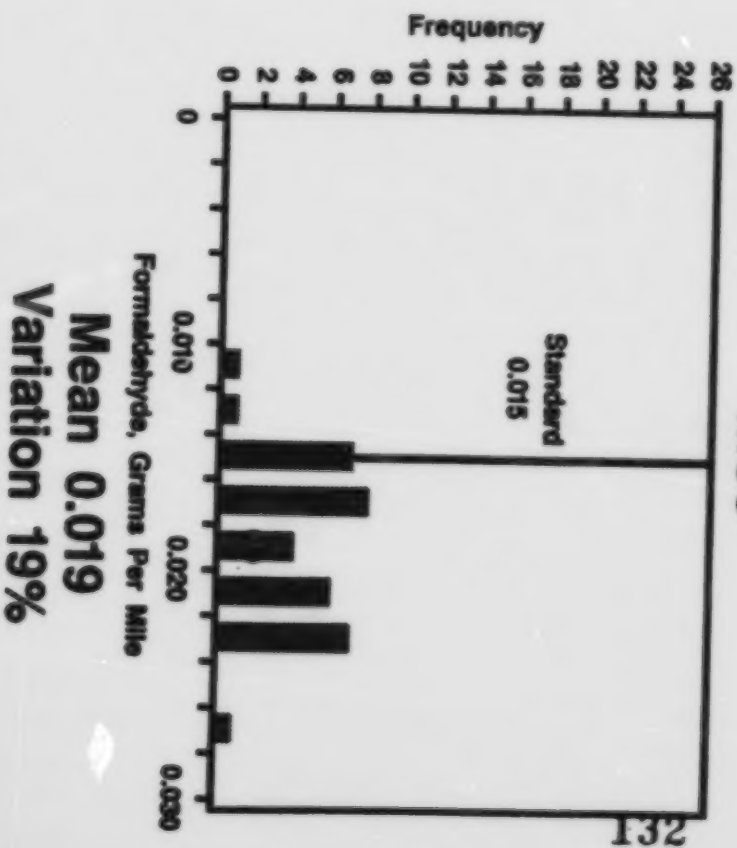
'75 FTP EMISSION TEST RESULTS

20 Variable-Fuel Corsicas - California Fleet

Gasoline



M85



AUTO / OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM

GM Variable-Fuel Test Fleet

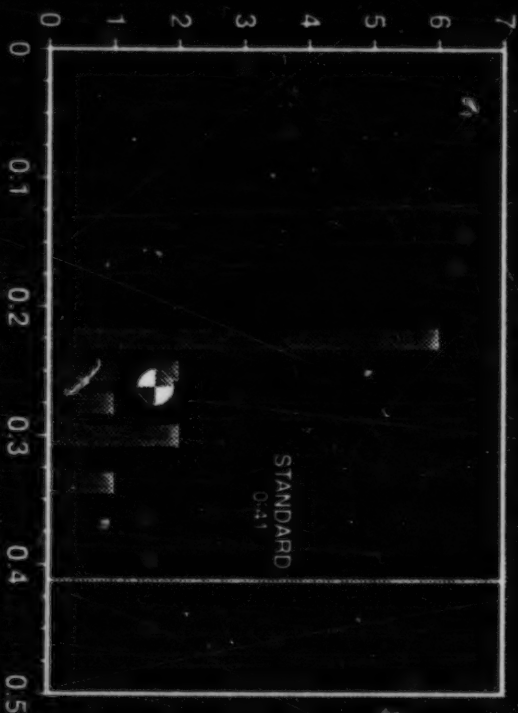
<u>VEHICLE</u>	<u>ENGINE</u>	<u>TRANS</u>	<u>FUEL SYSTEM</u>	<u>CATALYST</u>	<u>ODOMETER</u>
CORSICA	2.8L-V6	AUTO-3SP	SIMULTANEOUS PORT INJECTION	PRODUCTION UNDERFLOOR	33,200
CORSICA					21,200
CORSICA					10,200
CORSICA					10,200
CORSICA					10,100
CORSICA					10,100
LUMINA	3.1L-V6	AUTO-4SP	"	"	10,800
LUMINA					10,600

OMHCE Emissions - 6 VFV Corsicas

Part of Auto/Oil Research Test Fleet

Frequency

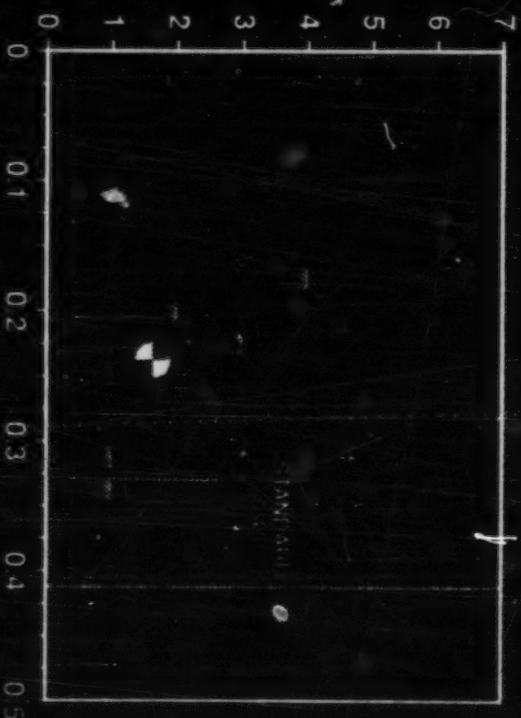
GASOLINE



MEAN 0.27
VARIATION 13%

Frequency

M85



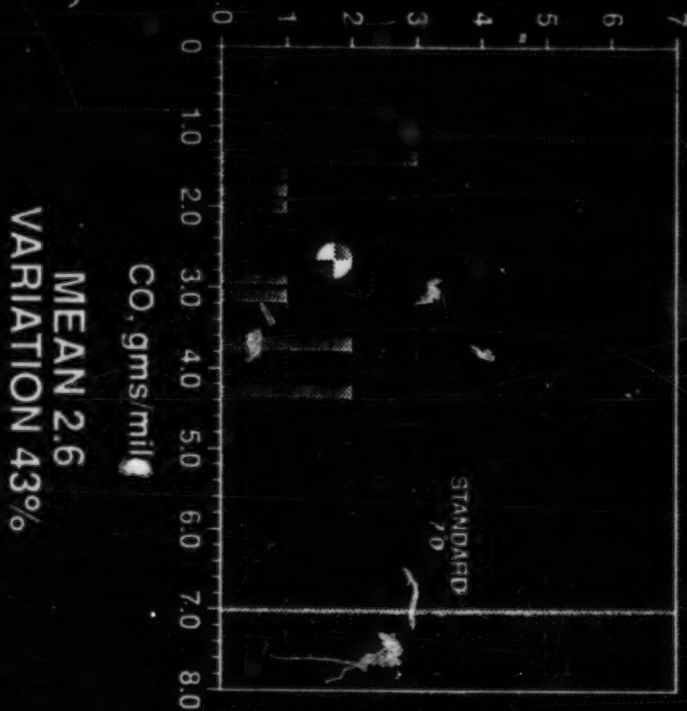
MEAN 0.23
VARIATION 21%

CO Emissions - 6 V6V Corsicas

Part of Auto/Oil Research Test Fleet

Frequency

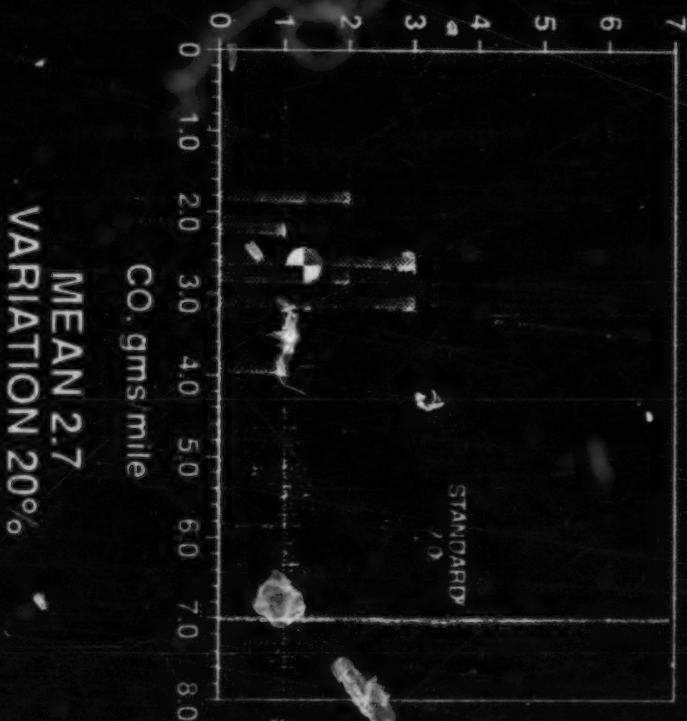
GASOLINE



MEAN 2.6
VARIATION 43%

Frequency

M85



MEAN 2.7
VARIATION 20%

NOx Emissions - 6 VFV Corsicas

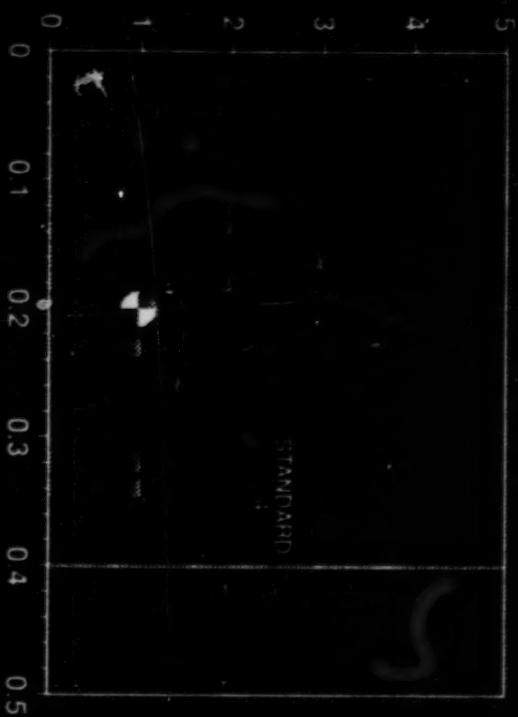
Part of Auto/Oil Research Test Fleet

Frequency

GASOLINE

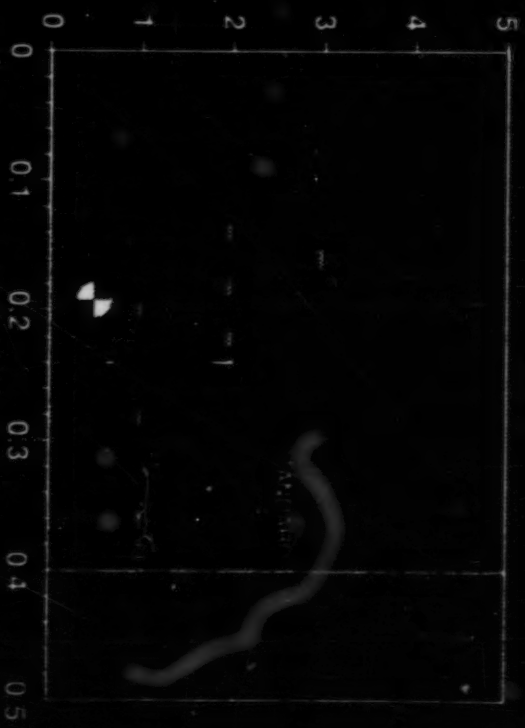
Frequency

M85



NOx, gms/mile

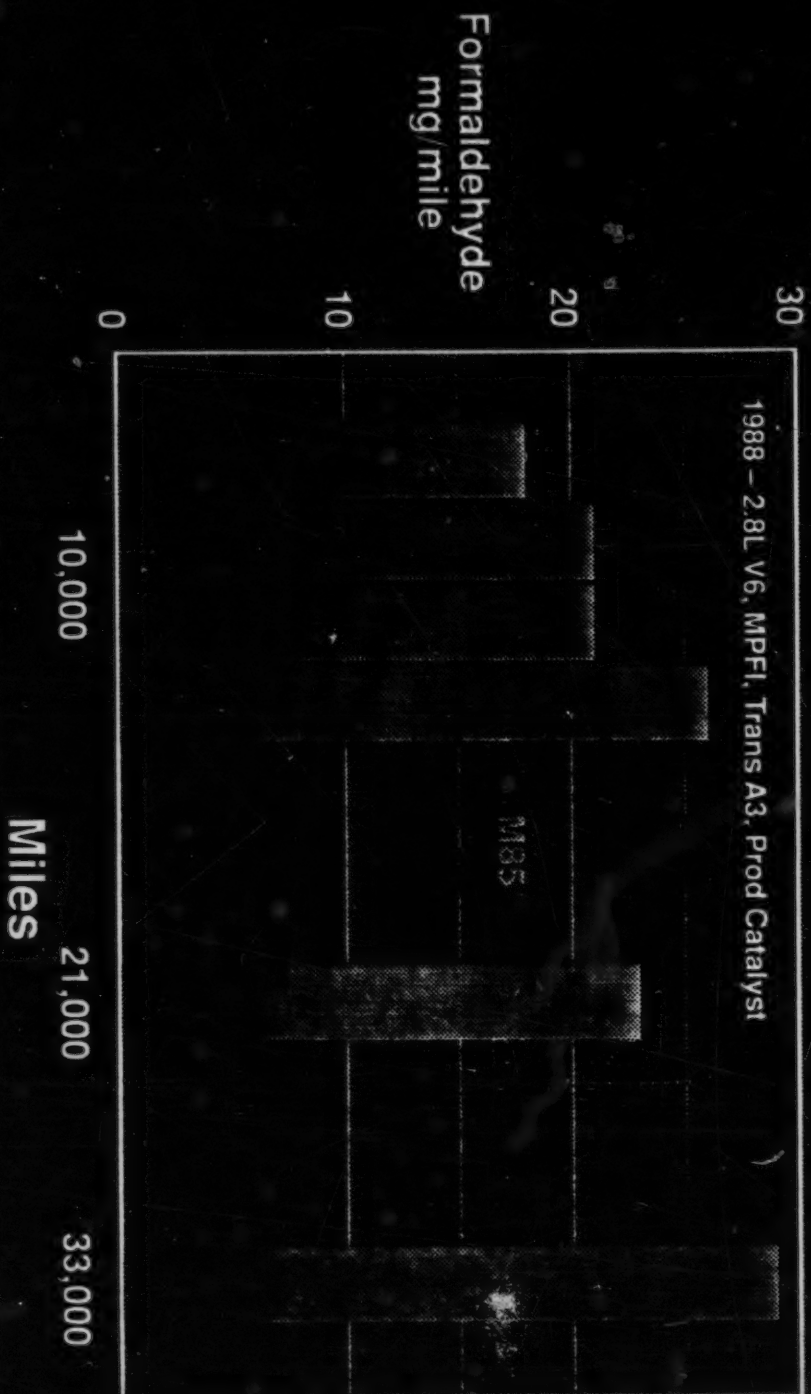
MEAN 0.2
VARIATION 37%

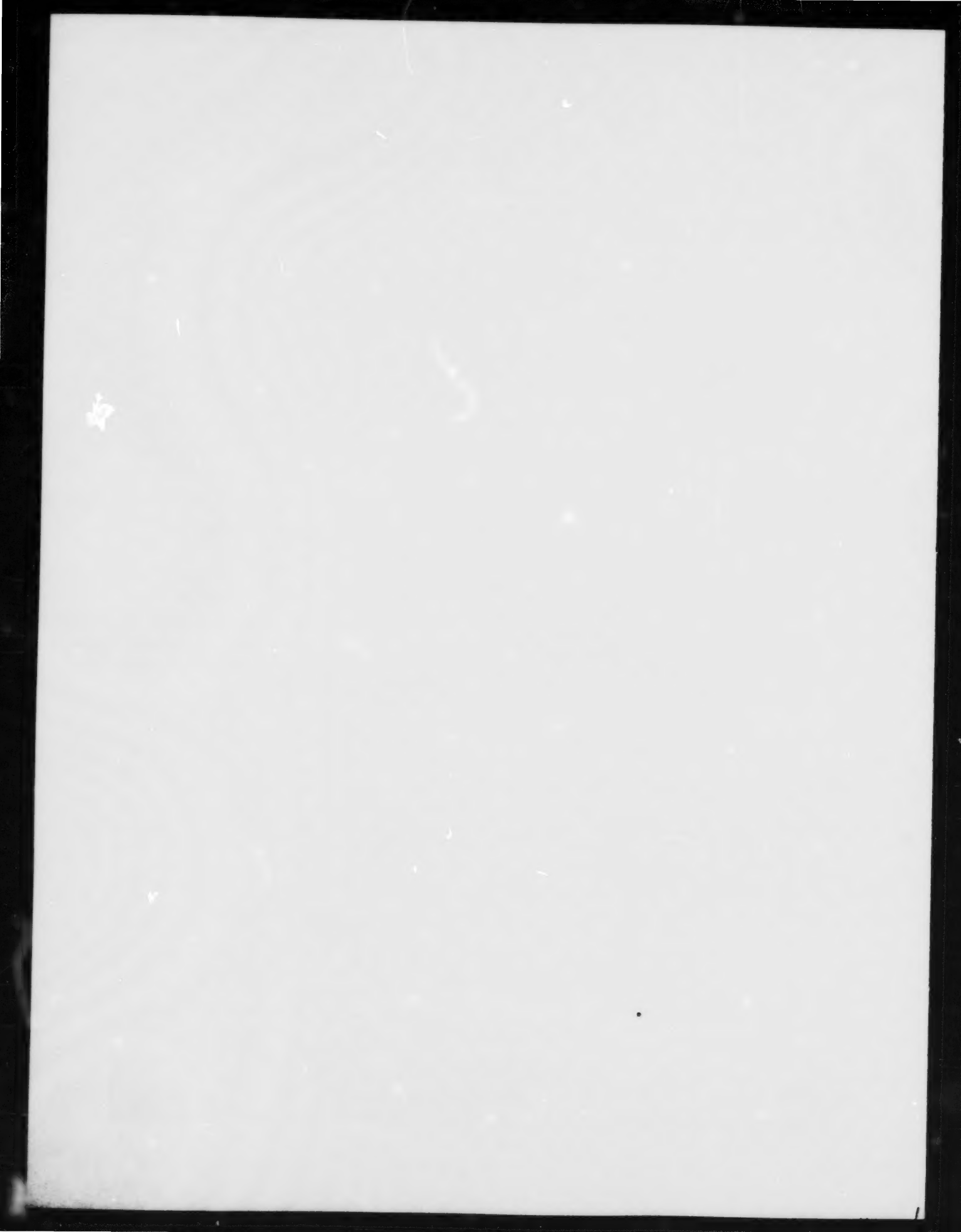


NOx, gms/mile

MEAN 0.2
VARIATION 30%

Formaldehyde Emissions 6 Variable-Fuel Corsicas Part of Auto/Oil Research Test Fleet





**NATURAL GAS VEHICLE DEVELOPMENTS—A
GAS INDUSTRY AND ORIGINAL EQUIPMENT
MANUFACTURER COOPERATIVE EFFORT**

Steven W. Gauthier, Gas Research Institute

ABSTRACT

For many years, natural gas has been used as an engine fuel in stationary prime movers driving natural gas compressors, liquid pumps, and similar equipment. However, the physical and economic barriers restricting the broad acceptance of natural gas as an alternative fuel in the transportation market have proven to be formidable. In spite of this, new opportunities for natural gas are being developed stimulated by energy security concerns, trade imbalances created by petroleum imports, the abundance of natural gas in North America and the existing transmission and distribution system that can deliver it to almost anywhere in the country, and, most importantly, tighter restrictions on vehicle emissions. Although substantial research and development will be required for natural gas to successfully meet the demands of the alternative-fuel vehicle marketplace, the clean burning characteristics of natural gas and the extensive experience gained in stationary gas engine development will help make natural gas vehicles a particularly attractive alternative. The gas industry, through the Gas Research Institute (GRI), is developing and implementing an R&D program to address this opportunity. GRI's efforts will focus on technology improvements for NGVs that will

exploit the environmental and performance benefits of natural gas as a vehicular fuel and will make gas the most cost effective option within the alternative fuels market.

INTRODUCTION

For many years, natural gas has been used as an engine fuel in stationary prime movers driving natural gas compressors, liquid pumps, and similar equipment. Natural gas has been particularly significant as a fuel for prime movers powering electric generators in the electric utility, commercial and industrial cogeneration sectors. To a lesser extent, natural gas has also been used in vehicles where there was a total operation cost advantage or other incentives. However, the physical and economic barriers restricting the broad acceptance of natural gas as an alternative fuel in the transportation market have proven to be formidable. The attributes of liquid petroleum products are so ideally suited to on-board fuel storage that vehicles using other than liquid petroleum fuel have gained only a minor market share in the United States. However, new opportunities for natural gas are being developed stimulated by energy security concerns, trade imbalances created by petroleum imports, the abundance of natural gas in North America and the

existing transmission and distribution system that can deliver it to almost anywhere in the country, and, most importantly, tighter restrictions on vehicle emissions. Although substantial research and development will be required for natural gas to successfully meet the demands of the alternative-fuel vehicle marketplace, the clean burning characteristics of natural gas and the extensive experience gained in stationary gas engine development will help make natural gas vehicles (NGV) a particularly attractive alternative.

The economic advantage of using natural gas as a vehicular fuel is more apparent in fleet operations, where a vehicle travels the same or similar route each day, and returns to the same location for refueling. This type of vehicle application allows an operator to accurately predict how much fuel will be required to complete his route, and also allows the costs of refueling to be spread over a larger number of vehicles. The high octane rating of natural gas offers additional technical advantages, allowing spark-ignited engine designs with higher compression ratios and energy efficiencies. However, in spite of the advantages offered by natural gas, storage, economic and institutional issues have hindered widespread use in vehicles.

The gas industry, through the Gas Research Institute (GRI), is developing and implementing an R&D program to address these concerns. GRI's efforts will focus on technology improvements for NGVs that will exploit the environmental and performance benefits of natural gas as a vehicular fuel and will make gas the most cost effective option within the alternative fuels market.

MARKET DRIVERS

In spite of this resistance to general market acceptance of NGVs, natural gas as a vehicle fuel may be highly desirable in markets driven by emissions restrictions. At the federal level, the U.S. Environmental Protection Agency (EPA) in 1985 promulgated regulations mandating reduced emissions levels from new gasoline and diesel engines for heavy-duty (HD) applications. These "technology forcing" standards, which conventional HD gasoline and diesel engines have not demonstrated they can meet with long term viability, will be applicable to HD engines produced in 1994 (1991 for transit buses) and beyond.

The probability of meeting these emissions standards in the near future with conventional diesel engine technology is uncertain. The prospects for near-term commercial availability of reliable, cost-effective HD catalytic converters and diesel particulate traps has yet to be demonstrated. Alternate fuels (including natural gas, propane, and methanol) are widely regarded as the most likely technical approach for the near-term. Although substantial research will be required to implement any one of these alternatives, the clean-burning characteristics, abundant supply, and competitive cost of natural gas make it a prime contender to meet EPA emissions standards.

The second force changing the outlook for natural gas vehicles is the failure by many metropolitan areas to attain compliance with the National Ambient Air Quality Standards (NAAQS) by the December 31, 1987 deadline. Of major concern are ozone and carbon monoxide compliance. Although temporary legislative relief from this deadline has been provided in some areas, the

burden shall remain on the local jurisdictions to submit plans describing their proposals to attain compliance. The EPA has previously announced that as a punitive measure it will seek non-compliance sanctions against construction of large facilities in Los Angeles. Other cities are being considered for similar sanctions. To address local air quality problems, legislation is being formulated in southern California, Texas, Oklahoma, New York State and other non-attainment areas, which will mandate the use of alternative motor fuels such as natural gas for heavy-duty and light-duty vehicles.

WHY NATURAL GAS VEHICLES

Natural gas provides a number of significant environmental and technical benefits. These include exhaust emissions with low photochemical reactivity (mainly non-reactive methane) (1), zero evaporative losses due to the pressure tight natural gas fueling system, and reduced cold-start and low-temperature emissions due to the elimination of cold enrichment since the natural gas remains in a gaseous state even at very low temperatures. (2)

Given the same emissions control technology, stoichiometric natural gas engines release significantly lower levels of reactive hydrocarbons than gasoline and diesel fueled engines and may also significantly reduce carbon monoxide emissions. In fact, the EPA estimates that natural gas vehicles can yield a 50 percent reduction in carbon monoxide emissions.(6) And application of lean burn technology may reduce NO_x emissions even further, to levels below those of conventional combustion. (3)

But even beyond these important

emissions benefits, natural gas offers safety and supply advantages as well. Over 40 years of extensive worldwide user experience with CNG vehicles has demonstrated the inherent safety and integrity of compressed natural gas storage tanks and refueling systems. Studies have revealed that although gasoline and CNG-powered vehicles have similar accident rates, the injury and death rate is much lower for CNG-powered vehicles. Analysis of CNG vehicle operations in Italy, where more than 300,000 are in service, have shown no deaths attributable to CNG fuel system failures.(7)

There are also noted technical advantages to using natural gas to fuel internal combustion engines. Its high octane rating, 120 to 130, allows operation at higher compression ratios than gasoline engines, which increases the energy efficiency of the engine and lowers the BTUs per mile required to operate a vehicle (4). The simple chemistry of natural gas results in less soot and deposits from combustion, leading to fewer contaminants in the lubricating oil, for reduced engine wear, and thus longer engine life.

GRI'S NGV PROGRAM STRATEGY

In order to ensure the viability of natural gas as a competitive option for transportation fuel, the GRI R&D strategy is responding to the emerging environmental regulations affecting both heavy-duty and light-duty diesel and gasoline vehicles. The program targets specific vehicle applications and represents a portfolio of development objectives to respond to the expected market opportunities opening up during the 1991 to 1994 period. The program is an emissions-based technology program. That is, it focuses on new technology that will allow vehicular

engines to meet current and emerging emissions standards. However, within this first priority, each project must address the economic and market viability of the development, and must identify a clear path to commercialization, to proceed.

The initial phases of the GRI program strategy emphasize large, heavy-duty vehicles and engines, with subsequent phases moving progressively toward vehicles powered by medium- and light-duty engines.

The near-term development objectives of the program are directly related to the timetable mandated by the EPA in their emissions regulations of 1985.

The first priority is to develop natural gas engine technologies for new and existing transit buses. New engine technologies are needed to meet the EPA 1991 bus emissions regulations, also, retrofit kits are needed to respond to potential emissions limitations from existing bus engines imposed by local jurisdictions. The second priority is the development of dedicated natural gas engines for application to fleet vehicles, such as route, delivery, and refuse trucks, to meet EPA, state, and local emissions regulations. Key technology issues are engine and fueling system improvements to ensure that natural gas can achieve low emissions goals, while maintaining good performance and driveability and providing durability and reliability comparable to diesel engines. In parallel with the engine development, GRI research will pursue the necessary ancillary equipment, such as compression/refueling station equipment and on-board storage systems, to provide the capability for gas users to capitalize on the economic and environmental benefits of using natural gas.

The participation of engine manufacturers, vendors, and the natural gas industry is critical to the success of GRI's NGV R&D effort. Participation by the potential suppliers of the natural gas engines in GRI's R&D efforts will reduce the time required for market application, spread the risk, and maximize commercialization potential. As a result, substantial cofunding is being pursued from the commercial participants, especially in research efforts that are characterized by lower technical and market risk.

GRI'S NGV R&D PROGRAM

GRI's research program is directed toward the development, testing, and implementation of dedicated natural gas vehicles optimized for low emissions and good performance. Heavy duty vehicle applications will be first targeted, with the focus of the program moving toward other, broader, applications. Specifically, the program is composed of five major development areas; 1) heavy duty transit buses, 2) medium/heavy-duty fleet vehicles, 3) light duty vehicles, 4) on-board natural gas storage systems, and 5) vehicle refueling systems.

Urban Transit Buses

GRI's primary thrust in urban bus applications is the development of a high performance, spark ignited, dedicated natural gas engine that responds directly to the 1991 EPA regulations. One of the leading developments in GRI's program is the natural gas version of the Cummins L10 diesel engine. To increase fuel economy and reduce emissions, this engine burns a lean fuel/air mixture, which contains more air than necessary to consume the fuel. To improve efficiency and promote more complete combustion, the combustion

	<u>NG L10</u>	<u>1991 Standards</u>
Emissions (gm/Bhp-hr)		
NOx	4.5	5.0
CO	<5.0	15.5
THC	<1.30*	1.3
Particulate	0.05	0.1
Performance		
Power	240 hp	---
Max Torque	750 ft-lbs	---
Efficiency	37%	---

Preliminary Results - Natural Gas L10 Engine
Table 1

* With Oxidation Catalyst

chambers are designed to create turbulence, causing higher flame speed. A new fuel-air management control system was developed for optimal performance under rigorous operating conditions. Preliminary results for the NG L10 (Table 1) indicate that it meets the current 1991 EPA emissions standards for transit buses. (5)

In a field evaluation phase several natural gas L10s are being installed in buses. Four transit buses, manufactured by Ontario Bus Industries, using this 10-liter, dedicated natural gas engine are being tested in the Toronto area with cooperation from Canada's Consumers Gas company. Two U.S. gas companies, Columbia Gas System and Consolidated Natural Gas Co., are demonstrating prototype buses that also use the Cummins L10 engine. These buses were built by the Flxible Corp., America's leading manufacturer of transit buses. Four of NG L10s will be tested in buses in southern California, two, built by Flxible, with South Coast Rapid Transit District and two, built by Gillig Coach, with Orange County Transit, all with the cooperation of Southern California Gas Company.

A NG L10 is also being tested in a different application, an urban

refuse hauler. The engine has been installed in a Crane Carrier refuse hauler operated by the New York City Department of Sanitation, which refuels at a Brooklyn Union Gas Company CNG refueling station.

Based on the results of laboratory tests, and the performance of the demonstration vehicles, Cummins has announced plans to offer the NG L10 for sale in 1990 in time to meet the 1991 standard.

In a more recently initiated project, with funding from GRI, Detroit Diesel Corporation (DDC) is developing a natural gas fueled version of their 6V92 diesel engine. This engine is the most commonly used engine in urban transit buses, as well as being used in other on and off-road applications. As with the NG L10 project, this development is focused at meeting the stringent emissions standards for transit buses while providing adequate power, performance and reliability. DDC is initially investigating several technologies which will allow the 6V92 to operate on natural gas including a Homogeneous Charge Auto-ignition concept, high pressure direct gas injection, and the use of spark ignition with a precombustion chamber on the engine.

A second thrust of the GRI transit bus engine program is targetted at developing a natural gas retrofit option for existing transit buses. The failure of many cities to comply with the Clean Air Act may result in emissions limitations on existing vehicles. Since urban buses are highly visible targets for such regulations, GRI is funding the development of a retrofit conversion system for the Detroit Diesel 6V92. Later this year, Denver RTD, with support from Public Service Company of Colorado, will begin testing five buses equipped with 6V92 engines modified for dual fuel operation by Stewart & Stevenson Services, Inc., Detroit Diesel's largest distributor. The modified version of the 6V92 being tested in Colorado uses a specially designed high pressure natural gas valve to inject natural gas through the cylinder wall to provide the majority of the fuel required to operate the engine. A small amount of diesel fuel is injected through the standard diesel injector, late in the compression stroke, to act as an ignition source to burn the natural gas (Figure 1). The goal is to greatly reduce visible smoke and particulate emissions from existing buses with a cost-effective retrofit system using natural gas for up to 85 percent of the engine's fuel requirements.

Medium/Heavy Duty Fleet Vehicles

The second focus of our natural gas vehicle program is the development of dedicated natural gas engines and advanced fueling systems for lighter duty fleet vehicles such as school buses, refuse haulers, and commercial delivery trucks. These medium/heavy duty vehicles are now powered by both diesel and gasoline engines. These fleets are ideal for natural gas use because their daily range is typically less than 150

miles, and they return each night to the same location for refueling. R&D in this area is directed at developing engines which meet stringent EPA, state and local emissions standards. GRI is working with a variety of engine and chassis manufacturers, and targetting a variety of applications.

In a cooperative research project with GRI, Hercules Engines, Inc. is developing a dedicated natural gas engine as a counterpart to its production model 3.7-liter, four-cycle diesel engine. Southwest Research Institute is developing lean-burn combustion technology for this engine. The engine is intended for truck classes 2b and 3, or of 8,500 to 14,000 pounds gross vehicle weight.

The American Bakers Association (ABA) and Entenmann's Inc., a large bakery, will participate in the project. Bakery fleets account for more than 10 percent of the delivery trucks and other vehicles in this size range (8,500 - 14,000 lb. gross vehicle weight), which are to be covered by new diesel emissions standards to be implemented by the Environmental Protection Agency in 1994. Major baking companies typically operate large fleets of vehicles that return to a central location each night, which makes it convenient for them to refuel with natural gas. The East Ohio Gas Co. has offered the use of its CNG filling stations for the field test. The gas company operates 11 stations in its territory, but will build another one if it should be needed for the test. ABA will monitor the performance, reliability, and durability of the natural gas engines and will provide guidance from a user's perspective.

United Parcel Service (UPS) and General Motors Corp. are cooperating on

participants.

Light-Duty Fleet Vehicles

GRI's near term development efforts will also include the development of a light-duty fleet vehicle. The proposed light duty initiative would target fleet vehicles such as vans and light-duty pick-up trucks, which are under 8500 lbs. GVW, and which nominally utilize engines from 3.9 to 5.9 liters in size. The initial market for these vehicles would be the major non-attainment areas in the U.S., such as Southern California, Houston, Denver, New York and other areas where there is strong incentive, both regulatory and environmental, to use alternative fuels.

This program will initially investigate utilizing existing and emerging engine developments to meet near term emission standards (1991-1994). A stoichiometric engine controlled by a state-of-the-art electronic closed loop engine controller would be employed along with a 3-way catalyst to control emissions.

Future work will focus on meeting more stringent emissions standards (1997 and beyond) and will investigate using advanced concepts and hardware. These might include advanced electronic engine control systems, port fuel injection, stratified charge combustion, and exhaust catalysts tailored to the emissions of NGVs.

On-Board Natural Gas Storage Systems

Because the size, weight, pressure, and energy density of CNG storage systems limit the vehicles' range and, thereby, its market applicability, GRI is pursuing the development

of improved natural gas adsorbent storage systems to contain the natural gas at lower pressures and/or higher densities. Cornell University is investigating the physical properties of low pressure adsorbents to identify the characteristics of an optimal storage media. Additionally, GRI is participating with the New York State Energy Research and Development Authority and the New York Gas Group in an ongoing program with the Linde Division of Union Carbide to develop an advanced storage media. The objectives of these projects are to achieve comparable natural gas storage at 500 psi as is currently achieved at 2400 to 3000 psi. The lower pressures also offer the benefit of reduced CNG compressor station capital and operating costs.

GRI has also recently solicited proposals to develop advanced high pressure CNG storage cylinders. This work will address the two major issues of concern, the high cost and heavy weight of currently available cylinders. Several proposals have been received from potential cylinder manufacturers proposing developments ranging from new materials of construction (full composite cylinder) to new methods of construction for traditional materials (electric resistance welded steel - epoxy/fiberglass wound cylinders). These proposals are being evaluated for development on selected projects to begin mid-1990.

Refueling Systems

This is the most recent area for R&D funding in the GRI NGV Program. GRI has identified several areas for new R&D initiatives in CNG refueling systems. These include compressors, compressor controls, high pressure quick fill meters and the full range of nozzles, receptacles and other

a project with Acurex Corp., co-sponsored by GRI, South Coast Air Quality Management District, California Energy Commission, New York State Energy Research and Development Authority, Southern California Gas Co. and Brooklyn Union Gas Co., to develop a GM 4.3-liter, V6 dedicated natural gas engine for UPS delivery trucks. The goal is to develop low-emission combustion technology to the point where the engine would not need conventional catalytic converters to meet emissions standards. This engine will employ lean-burn combustion technology and an advanced port fuel injection system under development at BKM, in San Diego, California. The engine will be controlled by a GM Delco electronic engine controller programmed specially for natural gas operation. This project will also investigate the merits of utilizing a "stratified charge" concept with this engine (Figure 2). The GM 4.3L engine is ideally suited for use in class 1 and 2 (up to 10,000 lbs. GVW) delivery trucks, for which GM foresees a substantial market in the future.

General Motors is also participating in other independent research projects on natural gas engines and fueling systems. In addition to supporting the development of the UPS truck engine with Acurex and GRI, GM is working with Tecogen Inc. and GRI to develop a natural gas fueled version of its 7-liter (427 cu. in.), V8 gasoline engine to be applied in medium-duty trucks, initially focusing on vehicles from 22,000 to 33,000 lbs. gross vehicle weight. The dedicated engine and fueling system will use the latest available emission control technology and computerized engine/fueling control system. It will be a naturally aspirated stoichiometric engine utilizing a natural gas throttle body fuel injection system

recently developed by Rochester Products. GM anticipates a number of market applications for this engine including delivery truck, school buses, paratransit vans and full size pick-up trucks.

As a future effort in the NGV program GRI is currently discussing with Mack Truck the development of a natural gas version of the Mack EM7-300G four stroke, diesel engine. The 12 liter, six cylinder, EM7 engine series is the newest generation of heavy duty diesels from Mack. In the natural gas program, the initial engine development will be done at Southwest Research Institute in San Antonio, Texas. The engine will utilize a learn burn approach, using conventional carburetion of natural gas with intake air, a novel, spark-ignited precombustion chamber and a unique ignition system under development by Magnavox. The objective of this project is to produce a clean-burning, natural gas version of the engine that will provide the same 300hp output as the original diesel engine, as well as maintain diesel torque and durability characteristics.

The immediate application for this engine is in refuse haulers. Some 5,000 refuse trucks are purchased in the United States every year, and Mack estimates they provide engines to about 50 percent of this market. Successful introduction of natural gas into this application will depend not only on engine development, but also on the ability to modify the chassis design to incorporate on-board storage cylinders without reducing refuse hauling capacity. Assuming project initiation this summer and success in both engine development and chassis design, field testing will begin in 1991, with BFI, a national refuse hauler, and Boston Gas in Massachusetts, as

fuel handling components used in CNG refueling systems. To help structure this program GRI will be initiating a CNG Refueling System Assessment project. The objective of this effort is to evaluate the current technical and economic status of compressed natural gas vehicle refueling stations and to identify the components or design features that offer the greatest potential for performance improvements and/or cost reductions. The scope of this solicitation includes transit bus refueling systems, refueling systems for light- or medium-duty vehicles in fleets of 10 or more, and individual vehicle refueling systems. Both slow- and rapid-fill systems are to be included.

The information obtained through this effort will be used to support GRI's natural gas vehicles R&D program planning and to help identify new R&D initiatives. In addition, the information on refueling economics will be used as input to analyses of transportation fuel markets, and to support R&D benefits analysis for any GRI-sponsored CNG refueling systems R&D.

SUMMARY

In conclusion, GRI believes substantial technological and market opportunities exist for natural gas in the transportation sector. These opportunities were stimulated by the environmental regulations affecting new vehicle emission control systems and by the plans by local jurisdictions to comply with the National Ambient Air Quality Standards of the Clean Air Act. These actions are causing restrictions to be placed on the use of heavy- and medium-duty diesel and gasoline vehicle engines. In response, GRI's NGV R&D program is targeting these applications for the initial introduction

of high performance, clean-burning, dedicated natural gas fueled vehicles. The objective of GRI's NGV R&D program is to develop the basis for a comprehensive system, from engine to fueling systems to on-board storage, that is a cost-competitive and environmentally attractive alternative to today's reliance on liquid petroleum products. However, to be successful the GRI program must be augmented by the active participation of both the gas industry and the equipment manufacturers and supplies. For GRI's program to be implemented, each project must identify a clear path to commercialization, through a team approach involving the manufacturer, end user, gas industry and GRI.

References

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- (3) Ditto, pp 3-4.
- (4) C.S. Weaver, "Natural Gas Vehicles - A Review Of The State Of The Art", Sierra Research Report No. SR89-04-01, pp 13; April 1989.
- (5) V. K. Duggal, "Overview and Progress Update of Natural Gas L-10 Engine Development", Presentation, Fifth Windsor Workshop on Alternative Fuels, June 1989.
- (6) U.S. Environmental Protection Agency, "Guidance on Estimating Motor Vehicle Emission Reductions from the Use of Alternative Fuels and Fuel Blends", U.S. EPA, EPA-AA-TSS-PA-87-4, January 29, 1988.

- (7) R. Klausmeier, "Assessment of Environmental, Health, and Safety Issues Related to the Use of Alternative Transportation Fuels", GRI Report GRI-89/0249, October, 1989.

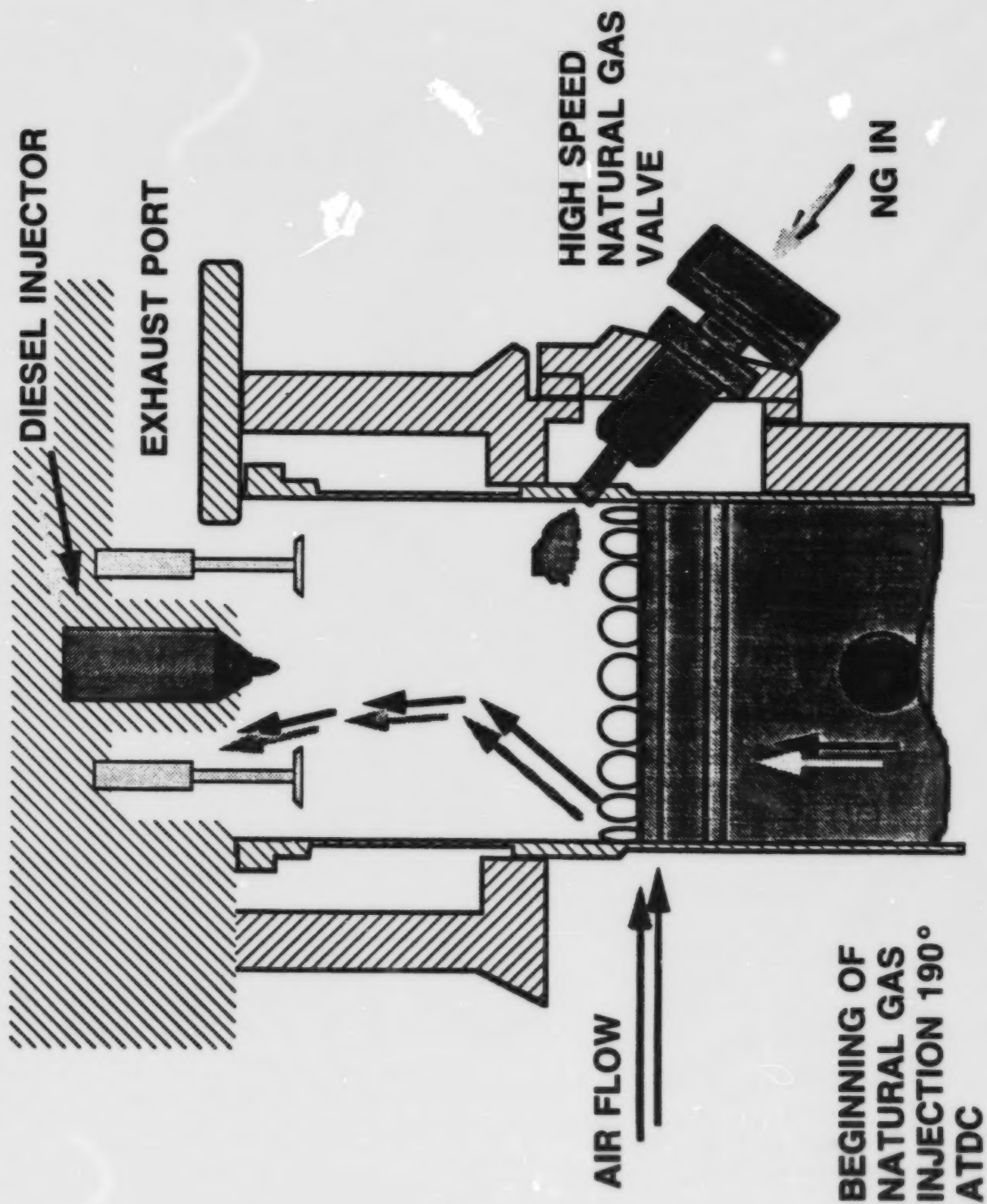
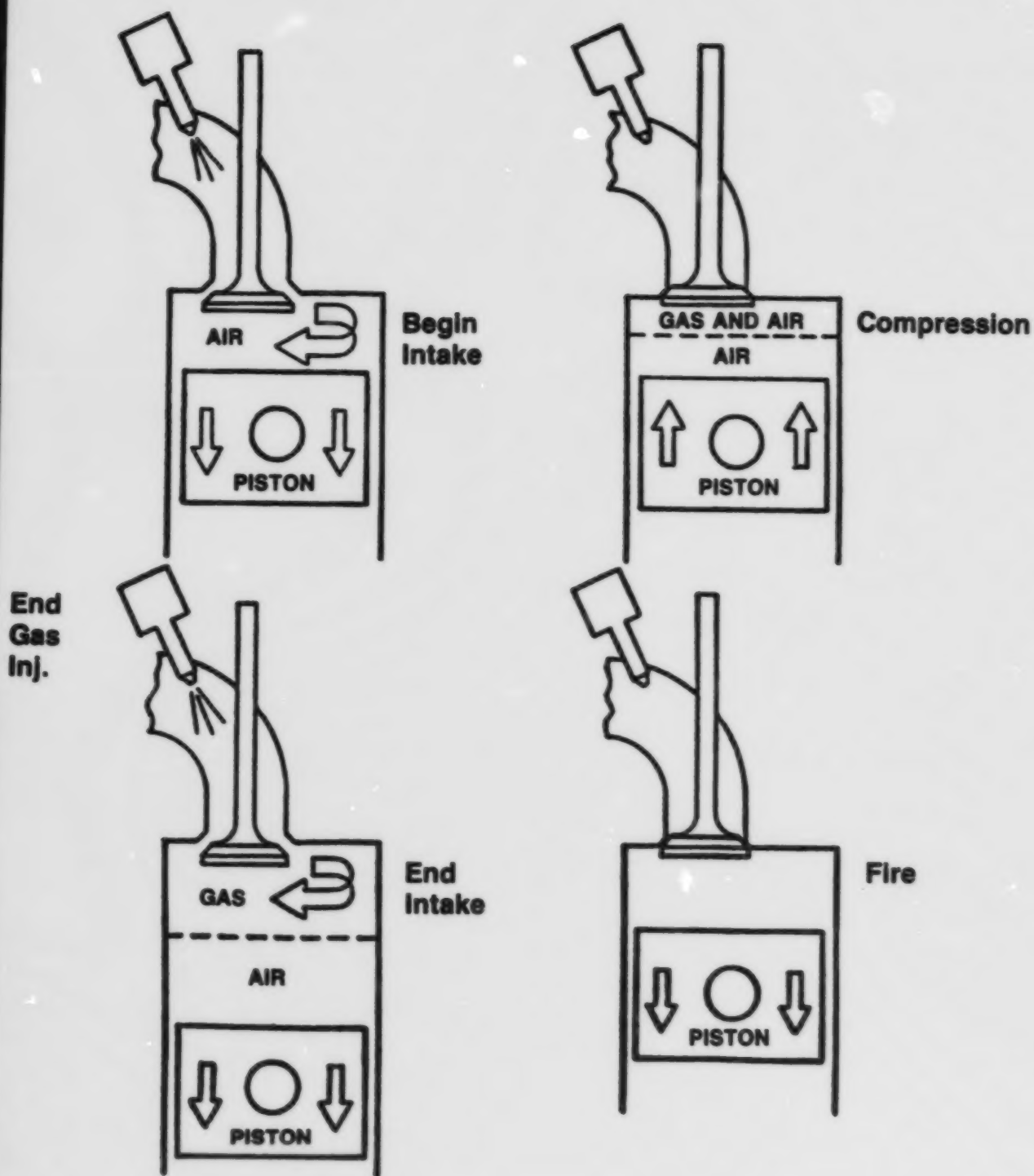


Figure 1



150
Figure 2

SESSION 2 - POLICY

Co-Chairs: Bernie James, Energy, Mines & Resources
Ron Graves, Oak Ridge National Laboratory

SUMMARY OF HEAVY DUTY DIESEL ENGINE LEGISLATION & REGULATION

J.E. Bennethum
Detroit Diesel Corporation

WINDSOR WORKSHOP

June 11-14, 1990
Toronto, Canada



CLEAN AIR ACT

ENACTED IN 1970, AMENDED 1977

**PROVIDES FRAMEWORK FOR REGULATORY
AND CERTIFICATION PROCESSES.**

1977 AMENDMENTS REQUIRED:

90% HYDROCARBON REDUCTION	-	(1.3 G/BHP-HR)
90% CARBON MONOXIDE REDUCTION	-	(15.5 G/BHP-HR)
75% NITRIC OXIDES REDUCTION	-	(1.7 G/BHP-HR)
PARTICULATE REDUCTION	-	GREATEST DEGREE ACHIEVABLE THRU APPLICATION OF TECHNOLOGY

**STATES TO OUTLINE METHODS FOR MEETING OZONE
AND CARBON MONOXIDE STANDARDS BY 1997.**

**TODAY 101 AREAS EXCEED OZONE STANDARDS
TODAY 44 AREAS EXCEED CO STANDARDS**

**IN 1987, EPA ISSUED A MODIFIED AIR QUALITY STANDARD
FOR PARTICULATES.**

TODAY 70 AREAS EXCEED THE PARTICULATE STANDARD



HISTORICAL U.S. HEAVY DUTY ENGINE EMISSION STANDARDS G/BHP-HR

GASEOUS

<u>M.Y.</u>	<u>NOx</u>	<u>HC</u>	<u>CO</u>	<u>PM</u>
1974	16	-	40	-
1979	10	1.5	25	-
1985	10.7	1.3	15.5	-
1988	10.7	1.3	15.5	0.60
1990	6.0	1.3	15.5	0.60

SMOKE OPACITY - %

<u>ACCELERATION</u>	<u>PEAK</u>	<u>LUG</u>
20	50	15

NOTES: 1974-84 NOx STANDARD WAS A NOx + HC COMBINED STANDARD
 1974-84 TEST CYCLE WAS A 13 MODE STEADY STATE TEST
 1985 AND LATER TEST CYCLE IS A TRANSIENT TEST



HISTORICAL

CALIFORNIA HEAVY DUTY ENGINE EMISSION STANDARDS G/BHP-HR

GASEOUS

<u>Y.</u>	<u>NOx</u>	<u>HC</u>	<u>CO</u>	<u>PM</u>
1973	16	-	-	-
1974	16	-	40	-
1975	10	-	30	-
1977	7.5	1.0	25	-
1980	6.0	1.0	15.5	-
1984	5.1	1.3	15.5	-
1988	6.0	1.3	15.5	0.60

NOTES: 1973-83 NOx STANDARD WAS A NOx + HC COMBINED STANDARD
 1974-83 TEST CYCLE WAS A 13 MODE STEADY STATE TEST
 1984 AND LATER TEST CYCLE IS A TRANSIENT TEST

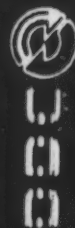


PROMULGATED HEAVY DUTY ENGINE EMISSION STANDARDS G/BHP-HR

<u>MY.</u>	<u>NOx</u>	<u>HC</u>	<u>CO</u>	<u>PM</u>
1991 TRUCKS	5.0	1.3	15.5	0.25
1991 URBAN BUS	5.0	1.3	15.5	0.10
1994 HEAVY DUTY	5.0	1.3	15.5	0.10

SMOKE OPACITY - %

<u>ACCELERATION</u>	<u>PEAK</u>	<u>LUG</u>
20	50	15



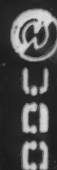
CLEAN AIR ACT REVISIONS

**CONGRESS IS EXPECTED TO PASS REVISIONS
TO THE CLEAN AIR ACT DURING 1990.**

THE HOUSE OF REPRESENTATIVES HAS PASSED HOUSE RULE 3030

THE SENATE HAS PASSED SENATE BILL 1630

**A HOUSE/SENATE CONFERENCE COMMITTEE WILL BE
CONVENED TO REACH A COMPROMISE ON A CLEAN AIR BILL**



EMISSION LEGISLATION STANDARDS

SENATE CLEAN AIR ACT REVISIONS SB1630

HOUSE CLEAN AIR ACT REVISIONS HR3030

NO SPECIFIED EMISSION STANDARDS

EPA RETAINS STANDARD SETTING AUTHORITY

DELETES 4 YEAR LEAD TIME REQUIREMENT

DELETES PERCENTAGE REDUCTION
REQUIREMENTS (75% NO_x & 90% HC & CO)

URBAN BUS

P.M. . . 1993 & AFTER 0.10 G/BHP-HR

EPA IS TO STUDY NEED FOR & FEASIBILITY
OF STANDARDS FOR TOXIC AIR POLLUTANTS,
STUDY FOCUSED ON FORMALDEHYDE,
BENZENE & 1,3 BUTADIENE



EMISSION LEGISLATION STANDARDS

SENATE CLEAN AIR ACT REVISIONS

SB1630

HIGHWAY TRUCK

NO_x ... 1991 - 1997 5.0 G/BHP-HR
1998 & AFTER 4.0 G/BHP-HR

HOUSE CLEAN AIR ACT REVISIONS HR3030

NO SPECIFIED EMISSION STANDARDS

EPA RETAINS STANDARD SETTING AUTHORITY

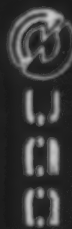
DELETES 4 YEAR LEAD TIME REQUIREMENT

DELETES PERCENTAGE REDUCTION
REQUIREMENTS (75% NO_x & 90% HC & CO)

URBAN BUS

PM₁₀ ... 1993 & AFTER 0.10 G/BHP-HR

EPA IS TO STUDY NEED FOR & FEASIBILITY
OF STANDARDS FOR TOXIC AIR POLLUTANTS,
STUDY FOCUSED ON FORMALDEHYDE,
BENZENE & 1,3 BUTADIENE



EMISSION LEGISLATION STANDARDS

SENATE CLEAN AIR ACT REVISIONS SB1630

P.M. . . 1981 - 1983 0.25 G/BHP-HR
1984 & AFTER 0.10 G/BHP-HR

HOUSE CLEAN AIR ACT REVISIONS HR3030

NO SPECIFIED EMISSION STANDARDS

EPA RETAINS STANDARD SETTING AUTHORITY

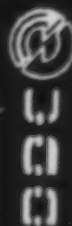
DELETES 4 YEAR LEAD TIME REQUIREMENT

DELETES PERCENTAGE REDUCTION
REQUIREMENTS (75% NO_x & 90% HC & CO)

URBAN BUS

P.M. . . 1993 & AFTER 0.10 G/BHP-HR

EPA IS TO STUDY NEED FOR & FEASIBILITY
OF STANDARDS FOR TOXIC AIR POLLUTANTS,
STUDY FOCUSED ON FORMALDEHYDE,
BENZENE & 1,3 BUTADIENE



EMISSION LEGISLATION STANDARDS

SENATE CLEAN AIR ACT REVISIONS

SB1630

URBAN BUSES
P.M. . . 1992 & AFTER 0.10 G/BHP-HR

HOUSE CLEAN AIR ACT REVISIONS

HR3030

NO SPECIFIED EMISSION STANDARDS

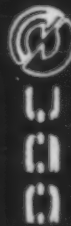
EPA RETAINS STANDARD SETTING AUTHORITY

DELETES 4 YEAR LEAD TIME REQUIREMENT

DELETES PERCENTAGE REDUCTION
REQUIREMENTS (75% NOx & 90% HC & CO)

URBAN BUS
P.M. . . 1993 & AFTER 0.10 G/BHP-HR

EPA IS TO STUDY NEED FOR & FEASIBILITY
OF STANDARDS FOR TOXIC AIR POLLUTANTS,
STUDY FOCUSED ON FORMALDEHYDE,
BENZENE & 1,3 BUTADIENE



EMISSION LEGISLATION STANDARDS

SENATE CLEAN AIR ACT REVISIONS SB1630

PROHIBITS EPA FROM REQUIRING
MORE STRINGENT STANDARDS
BEFORE JANUARY 1, 2002

HOUSE CLEAN AIR ACT REVISIONS HR3030

NO SPECIFIED EMISSION STANDARDS

EPA RETAINS STANDARD SETTING AUTHORITY

DELETES 4 YEAR LEAD TIME REQUIREMENT

DELETES PERCENTAGE REDUCTION
REQUIREMENTS (75% NOx & 90% HC & CO)

URBAN BUS

PM₁₀ . . 1993 & AFTER 0.10 G/BHP-HR

EPA IS TO STUDY NEED FOR & FEASIBILITY
OF STANDARDS FOR TOXIC AIR POLLUTANTS,
STUDY FOCUSED ON FORMALDEHYDE,
BENZENE & 1,3 BUTADIENE



EMISSION LEGISLATION

STANDARDS

SENATE CLEAN AIR ACT REVISIONS SB1630

NOX.....1991 - 1997 5.0 G/BHP-HR
NOX.....1998 AND AFTER 4.0 G/BHP-HR
PM.....1991 - 1993 0.25 G/BHP-HR
PM.....1994 AND AFTER 0.10 G/BHP-HR
PM.....1992 AND AFTER 0.10 G/BHP-HR
URBAN BUSES
o PROHIBITS EPA FROM REQUIRING MORE
 STRINGENT STANDARDS BEFORE
 JANUARY 1, 2002

o ALLOWS EPA TO ESTABLISH REGULATIONS
 FOR EMISSION AVERAGING, BANKING AND
 TRADING

HOUSE CLEAN AIR ACT REVISIONS HR3030

o NO SPECIFIED EMISSION STANDARDS
o EPA RETAINS STANDARD SETTING AUTHORITY
o DELETES 4 YEAR LEAD TIME REQUIREMENT
o DELETES PERCENTAGE REDUCTION REQUIREMENTS
 (75% NOx AND 90% HC AND CO)
o EPA IS TO STUDY NEED FOR AND FEASIBILITY
 OF STANDARDS FOR TOXIC AIR POLLUTANTS,
 STUDY FOCUSED ON FORMALDEHYDE, BENZENE
 AND 1,3 BUTADIENE

(05-30-90.06)

EMISSION LEGISLATION FUEL SPECIFICATION

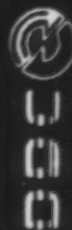
SENATE CLEAN AIR ACT REVISIONS SB1630

OCTOBER 1, 1993 ON-ROAD DIESEL FUEL TO
HAVE A MAXIMUM SULFUR CONTENT OF 0.05%
AND A MINIMUM CETANE INDEX OF 40

MAKES IT ILLEGAL TO FUEL A DIESEL FUELED
VEHICLE WITH A FUEL CONTAINING A SULFUR
LEVEL IN EXCESS OF 0.05%

HOUSE CLEAN AIR ACT REVISIONS HR3030

OCTOBER 1, 1993 ON-ROAD DIESEL FUEL TO
HAVE A MAXIMUM SULFUR CONTENT OF 0.05%
AND A MINIMUM CETANE INDEX OF 40



EMISSION LEGISLATION

NON-ROAD ENGINES

SENATE CLEAN AIR ACT REVISIONS
SB1630

HOUSE CLEAN AIR ACT REVISIONS
HR3030

- o REQUIRES EPA TO STUDY IMPACT OF EMISSIONS FROM NON-ROAD ENGINES AND PROVIDES EPA THE AUTHORITY TO REGULATE.
- o EPA PROVIDED 2 YEARS TO PUBLISH A LIST OF CATEGORIES OF NON-ROAD VEHICLES ALONG WITH ESTIMATES OF EMISSIONS CONTRIBUTION. UPON DETERMINATION OF NEED EPA TO PROMULGATE STANDARDS.

- o REQUIRES EPA TO STUDY IMPACT OF EMISSIONS FROM NON-ROAD ENGINES AND PROVIDES EPA THE AUTHORITY TO REGULATE.
- o PROHIBITS STATES FROM SETTING SEPARATE STANDARDS FOR NON-ROAD ENGINES OR VEHICLES.
- o EPA PROVIDED 4 YEARS TO PROMULGATE REGULATIONS:

18 MONTHS TO COMPLETE STUDY
12 MONTHS TO DETERMINE NEED
18 MONTHS TO PROMULGATE REGULATIONS

EMISSION LEGISLATION ALTERNATIVE FUELS

HR3030

**DEFINES CLEAN ALTERNATIVE FUEL AS METHANOL OR OTHER ALCOHOLS,
REFORMULATED GASOLINE, DIESEL, NATURAL GAS, LIQUEFIED PETROLEUM
GAS OR POWER SOURCE USED IN A CLEAN FUEL VEHICLE THAT COMPLIES
WITH THE APPLICABLE STANDARDS.**



EMISSION LEGISLATION ALTERNATIVE FUELS

HR3030

DEFINES CLEAN ALTERNATIVE FUEL AS METHANOL OR OTHER ALCOHOLS, REFORMULATED GASOLINE, DIESEL, NATURAL GAS, LIQUEFIED PETROLEUM GAS OR POWER SOURCE USED IN A CLEAN FUEL VEHICLE THAT COMPLIES WITH THE APPLICABLE STANDARDS.

APPLICABLE TO NEW URBAN BUSES IN MSA'S OF 750,000 OR MORE POPULATION AND HEAVY DUTY TRUCKS 28,500 POUNDS OPERATED IN CENTRALLY FUELED FLEETS (OR ARE CAPABLE OF BEING CENTRALLY FUELED) OF 10 OR MORE VEHICLES. DOES NOT INCLUDE EMERGENCY, LEASE OR RENTAL VEHICLES.

PHASE IN SCHEDULE:

25% IN 1994 M.Y.

60% IN 1995 M.Y.

100% IN 1996 M.Y.



EMISSION LEGISLATION ALTERNATIVE FUELS

HR3030

**EPA TO SET STANDARDS FOR CLEAN FUEL VEHICLES SO THAT EITHER NOX
OR PARTICULATE DOES NOT EXCEED 50% OF THE EMISSION STANDARD
APPLICABLE TO CONVENTIONALLY FUELED HEAVY DUTY ENGINES.**

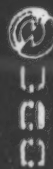


EMISSION LEGISLATION ALTERNATIVE FUELS

HR3030

EPA TO SET STANDARDS FOR CLEAN FUEL VEHICLES SO THAT EITHER NOX OR PARTICULATE DOES NOT EXCEED 50% OF THE EMISSION STANDARD APPLICABLE TO CONVENTIONALLY FUELED HEAVY DUTY ENGINES.

EPA HAS THE AUTHORITY TO REQUIRE EXISTING URBAN BUSES IN MSA'S OF 750,000 OR MORE POPULATION WHICH HAVE ENGINES REBUILT OR REPLACED TO OPERATE ON CLEAN FUELS AFTER JANUARY 1, 1996.



EMISSION LEGISLATION ALTERNATIVE FUELS

HR3030

EPA TO SET STANDARDS FOR CLEAN FUEL VEHICLES SO THAT EITHER NOX OR PARTICULATE DOES NOT EXCEED 50% OF THE EMISSION STANDARD APPLICABLE TO CONVENTIONALLY FUELED HEAVY DUTY ENGINES.

EPA HAS THE AUTHORITY TO REQUIRE EXISTING URBAN BUSES IN MSA'S OF 750,000 OR MORE POPULATION WHICH HAVE ENGINES REBUILT OR REPLACED TO OPERATE ON CLEAN FUELS AFTER JANUARY 1, 1996.

VEHICLES OVER 8,500 POUNDS IN CENTRALLY FUELED FLEETS LOCATED IN OZONE NON-ATTAINMENT AREAS OF 250,000 POPULATION OR MORE WILL BE REQUIRED TO BE CLEAN FUELED. THE FOLLOWING SCHEDULE HAS BEEN ESTABLISHED:

30% IN 1998 M.Y.

50% IN 1999 M.Y.

70% IN 2000 M.Y.



EMISSION LEGISLATION ALTERNATIVE FUELS

SB1630

**DEFINES CLEAN ALTERNATIVE FUEL AS METHANOL OR A MIXTURE CONTAINING
METHANOL AND GASOLINE, ETHANOL OR A MIXTURE CONTAINING ETHANOL
AND GASOLINE, REFORMULATED GASOLINE, NATURAL GAS, LIQUEFIED
PETROLEUM GAS, ELECTRICITY, OR ANY OTHER FUEL OR POWER SOURCE
WHICH COMPLIES WITH STANDARDS.**

EMISSION LEGISLATION ALTERNATIVE FUELS

SB1630

DERIVES CLEAN ALTERNATIVE FUEL AS METHANOL OR A MIXTURE CONTAINING METHANOL AND GASOLINE, ETHANOL OR A MIXTURE CONTAINING ETHANOL AND GASOLINE, REFORMULATED GASOLINE, NATURAL GAS, LIQUEFIED PETROLEUM GAS, ELECTRICITY, OR ANY OTHER FUEL OR POWER SOURCE WHICH COMPLES WITH STANDARDS.

APPLICABLE TO NEW URBAN BUSES IN MSA'S OF 1,000,000 OR MORE POPULATION BEGINNING WITH THE 1997 MODEL YEAR. THIS INCLUDES 70 CITIES WITH OVER 70% OF THE TRANSIT BUSES.

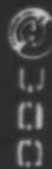
PHASE IN SCHEDULE:

MSA's $\geq$ 1,500,000

10% IN 1991 M.Y.
25% IN 1992 M.Y.
60% IN 1993 M.Y.
100% IN 1994 M.Y.

MSA's $\geq$ 1,000,000

10% IN 1993 M.Y.
25% IN 1995 M.Y.
60% IN 1996 M.Y.
100% IN 1997 M.Y.



EMISSION LEGISLATION ALTERNATIVE FUELS

SB1630

DEFINES CLEAN ALTERNATIVE FUEL AS METHANOL OR A MIXTURE CONTAINING METHANOL AND GASOLINE, ETHANOL OR A MIXTURE CONTAINING ETHANOL AND GASOLINE, REFORMULATED GASOLINE, NATURAL GAS, LIQUEFIED PETROLEUM GAS, ELECTRICITY, OR ANY OTHER FUEL OR POWER SOURCE WHICH COMPLES WITH STANDARDS.

APPLICABLE TO NEW URBAN BUSES IN MSA'S OF 1,000,000 OR MORE POPULATION BEGINNING WITH THE 1997 MODEL YEAR. THIS INCLUDES 70 CITIES WITH OVER 70% OF THE TRANSIT BUSES.

PHASE IN SCHEDULE:

<u>MSA'S $\geq$ 1,500,000</u>	<u>MSA'S $\geq$ 1,000,000</u>
10% IN 1991 M.Y.	10% IN 1993 M.Y.
25% IN 1992 M.Y.	25% IN 1995 M.Y.
60% IN 1993 M.Y.	60% IN 1996 M.Y.
100% IN 1994 M.Y.	100% IN 1997 M.Y.

EPA TO PROMULGATE REGULATIONS EFFECTIVE WITH THE 1992 M.Y. REQUIRING ANY URBAN BUS OPERATING IN ONE OF THE MSA'S SPECIFIED AT THE TIME OF MAJOR ENGINE OVERHAUL TO BE RETROFITTED SO AS TO COMPLY WITH THE EMISSION STANDARDS APPLICABLE TO 1992 NEW URBAN BUSES.



EMISSION LEGISLATION ALTERNATIVE FUELS

SB1630

DEFINES CLEAN ALTERNATIVE FUEL AS METHANOL OR A MIXTURE CONTAINING METHANOL AND GASOLINE, ETHANOL OR A MIXTURE CONTAINING ETHANOL AND GASOLINE, PROPANE, NATURAL GAS, LIQUEFIED PETROLEUM GAS, ELECTRICITY, OR ANY OTHER FUEL OR POWER SOURCE WHICH COMPLES WITH STANDARDS.

APPLICABLE TO NEW URBAN BUSES IN MSA'S OF 1,000,000 OR MORE POPULATION BEGINNING WITH THE 1987 MODEL YEAR. THIS INCLUDES 70 CITIES WITH OVER 70% OF THE TRANSIT BUSES.

PHASE IN SCHEDULE:

MSA'S $\geq$ 1,500,000
100% IN 1991 M.Y.
25% IN 1992 M.Y.
60% IN 1993 M.Y.
100% IN 1994 M.Y.

MSA'S $\geq$ 1,000,000
10% IN 1993 M.Y.
25% IN 1995 M.Y.
60% IN 1996 M.Y.
100% IN 1997 M.Y.

EPA TO PROMULGATE REGULATIONS EFFECTIVE WITH THE 1992 M.Y. REQUIRING ANY URBAN BUS OPERATING IN ONE OF THE MSA'S SPECIFIED AT THE TIME OF MAJOR ENGINE OVERHAUL TO BE RETROFITTED SO AS TO COMPLY WITH THE EMISSION STANDARDS APPLICABLE TO 1992 NEW URBAN BUSES.

REQUIRES HEI TO COMPLETE AN ANALYSIS OF THE CARCINOGENIC EFFECT ASSOCIATED WITH THE USE OF METHANOL



STATE CLEAN FUEL LEGISLATION

ARIZONA (SIGNED)

REQUIRES THE USE OF CLEAN BURNING FUELS IN BUSES PURCHASED FOR OPERATION IN NON-ATTAINMENT AREAS. A PHASE IN PROGRAM REQUIRES 10% OF BUSES PURCHASED IN 1990; 20% IN 1991, 35% IN 1992, 75% IN 1993 AND 100% THEREAFTER. CLEAN BURNING FUELS INCLUDE CNG, LPG, METHANOL OR ETHANOL.

CALIFORNIA (IN COMMITTEE)

REQUIRES THE PUBLIC UTILITIES COMMISSION TO EVALUATE AND IMPLEMENT POLICIES TO PROMOTE THE DEVELOPMENT OF EQUIPMENT AND INFRASTRUCTURE NEEDED TO FACILITATE THE USE OF ELECTRIC POWER AND NATURAL GAS TO FUEL LOW EMISSION VEHICLES.

REQUIRES ARB TO ADOPT REGULATION TO ACHIEVE MAXIMUM FEASIBLE REDUCTION IN EMISSIONS FROM EXISTING HEAVY-DUTY VEHICLES.

PROVIDES AUTHORITY TO ANY NON-ATTAINMENT DISTRICT TO REQUIRE FLEETS OF 15 OR MORE VEHICLES TO PURCHASE LOW-EMISSION VEHICLES.

COLORADO (PASSED BOTH HOUSES)

REQUIRES 1992 OR LATER MODEL YEAR VEHICLES PURCHASED BY THE STATE, STATE AGENCIES, OR ANY POLITICAL SUBDIVISION TO OPERATE ON "CLEAN BURNING ALTERNATIVE FUEL," DEFINED AS NATURAL GAS, LPG, E-85, M-85, ELECTRICITY OR OTHER ALTERNATIVE FUEL APPROVED BY THE COLORADO AIR QUALITY CONTROL COMMISSION.



STATE CLEAN FUEL LEGISLATION (Continued)

LOUISIANA (IN COMMITTEE)

REQUIRES USE OF CNG OR OTHER ALTERNATIVE FUELS WHICH RESULT IN COMPARABLY LOWER EMISSIONS OF NO_x, VOC, CO OR PARTICULATES IN STATE GOVERNMENT VEHICLES PURCHASED AFTER SEPTEMBER 1, 1991.

OKLAHOMA (USE FOR LEGISLATIVE APPROVAL)

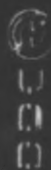
REQUIRES THE USE OF NATURAL GAS, LPG OR OTHER FUELS CAPABLE OF PRODUCING COMPARABLY LOWER EMISSIONS, IN NEW SCHOOL BUSES AND REQUIRES CONVERSION OF EXISTING GASOLINE SCHOOL BUSES TO A CLEAN FUEL. THE REQUIREMENT WOULD BE EFFECTIVE 5 YEARS AFTER PASSAGE.

PENNSYLVANIA (IN COMMITTEE)

REQUIRES STATE TO PURCHASE VEHICLES WHICH OPERATE ON ALTERNATIVE MOTOR FUELS AND REQUIRES A STUDY OF THESE VEHICLES TO BE PRESENTED TO THE GOVERNOR BY JANUARY 1, 1993.

TEXAS (SIGNED)

REQUIRES SCHOOL DISTRICTS, STATE AGENCIES AND METROPOLITAN TRANSIT AUTHORITIES AFTER SEPTEMBER 1, 1991 TO PURCHASE OR LEASE VEHICLES CAPABLE OF USING CNG OR OTHER FUELS WITH SIMILAR EMISSION CHARACTERISTICS. REQUIRES AFFECTED ENTITIES TO ACHIEVE SPECIFIED QUANTITIES OF ALTERNATIVE FUELED VEHICLES BETWEEN 1994 AND 1998.



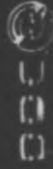
STATE CLEAN FUEL LEGISLATION (Continued)

PENNSYLVANIA, SOUTH DAKOTA, VIRGINIA (SIGNED)

STATES HAVE ADOPTED OR HAVE PENDING LEGISLATION URGING CONGRESS TO ENACT LEGISLATION TO MANDATE A PHASED SHIFT TO ALTERNATIVE FUELS AND TO PROVIDE FUNDING.

VIRGINIA (SIGNED)

ESTABLISH A JOINT SUBCOMMITTEE TO STUDY THE USE OF VEHICLES POWERED BY CLEAN TRANSPORTATION FUELS.



EMISSION LEGISLATION

SENATE CLEAN AIR ACT REVISIONS SB1630

EPA, DOE & UNTA DIRECTED TO ESTABLISH A RESEARCH & TECHNOLOGY CENTER AT A HIGH ALTITUDE CENTER FOR DEVELOPING & EVALUATING LESS POLLUTING HEAVY DUTY ENGINES & FUELS.

REQUIRES EPA TO CONTRACT A LABORATORY TO EVALUATE THE FEASIBILITY, ENGINE PERFORMANCE, EMISSIONS & PRODUCTION CAPABILITY OF AN ALTERNATIVE TO DIESEL FUEL COMPOSED OF ETHANOL & HIGH ERUCIC RAPSEED OIL.

PROVIDES EPA AUTHORITY TO REQUIRE ON-BOARD ENGINE DIAGNOSTIC SYSTEMS.

PROVIDES EPA AUTHORITY TO REQUIRE MANUFACTURERS TO PAY THE COSTS INCURRED IN PROCURING & TESTING IN-USE ENGINES.

PROVIDES EPA AUTHORITY TO USE DATA FROM STATE IAM PROGRAMS IN DETERMINING IN-USE NONCONFORMITY.

HOUSE CLEAN AIR ACT REVISIONS HR3030

EPA DIRECTED TO ESTABLISH A HIGH ALTITUDE TESTING CENTER TO DETERMINE WHETHER ENGINES COMPLY WITH STANDARDS THROUGH THEIR USEFUL LIFE.

PROVIDES EPA AUTHORITY TO REQUIRE ON-BOARD ENGINE DIAGNOSTIC SYSTEMS.

PROVIDES EPA AUTHORITY TO REQUIRE MANUFACTURERS TO PAY THE COSTS EPA INCURS WITH CERTIFICATION, END OF LINE & IN-USE TESTING.

PROVIDES EPA AUTHORITY TO CONTROL REBUILDING PRACTICES TO INCLUDE SETTING STANDARDS FOR REBUILT ENGINES.



SUMMARY

1. **CAA DECISION WILL BE SIGNED IN 1990**
2. **1981 URBAN BUS STANDARD WILL BE DELAYED**
3. **0.05% SULFUR FUEL COMMERCIALLY AVAILABLE**
4. **EPA WILL BE GIVEN AUTHORITY TO REGULATE
NON-ROAD EMISSIONS**
5. **MANDATED PHASE-IN OF ALTERNATE FUELS FOR
URBAN BUSES COULD BE EXTENDED TO CENTRALLY
FUELED FLEETS**
6. **EXPECT ADDITIONAL STATE LEGISLATION
COVERING CLEAN FUELS**



**Congressional Perspective on the Role of
Alternative Fuels in the United States**

Statement of

R. P. Staiger, Jr.

**Subcommittee on Energy and Power
Committee on Energy and Commerce
U. S. House of Representatives
Washington, DC 20515**

before

**1990 Windsor Workshop on
Alternative Fuels
Toronto, Canada**

June 12, 1990

Congressional Perspective on the Role of Alternative Fuels in the United States

Introduction

Perspectives on alternative fuels vary widely through the Congress. There is no single perspective that characterizes the the diverse views of Members from different geographic regions, varied backgrounds and diverse experiences. There are a variety of perspectives that have overlapping objectives and goals. The single common denominator is that for purposes of public policy debate today, alternative fuels usually means alternative fuels for use in transportation vehicles.

Energy Security Perspective

The first perspective considers alternative fuels as an energy security measure. Alternative fuels substitution for crude oil-based transportation fuels is viewed as a way to achieve improved United States energy security. Transportation is essential to the United States economy and transportation is totally dependent on liquid petroleum-based fuels.

The Department of Energy's Energy Information Agency predicts that oil imports will be 45% of consumption in 1990 and are expected to rise to 55% by 2000. Approximately half of our oil consumption is used by transportation.

Some progress has been made in addressing transportation's total dependence on crude oil fuels. In 1976 the average miles traveled per gallon of fuel was 13.1 m.p.g. Today, it is over 18 m.p.g. and rising as older, less efficient vehicles are gradually removed from service. This is a positive step towards minimizing transportation's unique dependence on imported oil. Unfortunately, it is only part of the picture.

While the efficiency of vehicles has improved, other facts have worked to increase the quantity of transportation fuels used:

- o Vehicle miles traveled are up from 1.3 trillion miles in 1976 to 2.0 trillion miles in 1988.
- o Fuel consumed by transportation vehicles is up from 109 billion gallons in 1976 to 131 billion gallons in 1988.
- o "Gas guzzler" tax receipts were \$116.8 million in 1988, an indication that some consumers are willing to pay a significant penalty to drive a big or inefficient car.
- o 7% of Americans went to work by public transportation in 1979. Today, the figure is 5% and dropping.

The conclusion that should be drawn from these figures is that Americans have vehicles with improved efficiency, but increasing numbers of Americans are driving further and using more oil for transportation. United States dependence on imported crude oil for transportation is getting worse, not better.

Transportation is uniquely vulnerable since transportation is almost entirely dependent on crude oil-based fuels. Other sectors of the economy have several sources of energy available. Industry can and does choose to meet its energy requirements by a combination of reliance on oil, gas, and coal; industry frequently designs its plants and equipment so it can shift between fuels based on price or availability. Residences and commercial usage have the additional option of choosing to rely on electricity for their energy needs. Electric utilities can choose from all fossil fuels as well as nuclear, hydro, and to some extent, renewables. The transportation sector of the economy has no choices. When a consumer purchases a new automobile, he or she can choose from an array of manufacturers, styles, engines, colors and other options. However, the consumer cannot make a choice of fuels. New vehicles run on gasoline or diesel fuels.

Proponents of this perspective usually consider alcohols and natural gas as the most attractive alternatives.¹ Proponents of this view assume that methanol was viewed as the likely alternative alcohol fuel. Ethanol made from bio-mass is viewed as too expensive to be used as a neat or near-neat fuel. Advocates of methanol recognize that most methanol will be imported but still believe the diversity in import supplies will make a significant contribution to energy security.

Sharp-Rockefeller Bill

The energy security perspective is embodied by the Sharp-Rockefeller bill now ~~formerly~~ known as the Alternative Motor Fuels Act of 1988 or P.L.100-494.

The major provisions are:

- o An authorization of \$12 million for the federal government to purchase the maximum feasible number of alternative-fueled automobiles and light duty trucks starting in Fiscal Year 1990 through Fiscal Year 1993, an authorization of \$2 million for demonstration of methanol and CNG use in urban mass transit busses, and an authorization of \$4 million for commercial demonstration of methanol and CNG use in heavy duty applications.
- o The establishment of an Interagency Commission on Alternative Motor Fuels to coordinate all the work within the Federal government related to alternative transportation fuels.
- o Establishment of a private sector advisory panel to allow local and state governments and private sector organizations an easy opportunity to participate in the development of alternative fuel policy and program development.
- o The establishment of a Federal incentive to encourage the production of alternative-fueled vehicles through the

¹ The Sharp-Rockefeller bill defined alcohol fuel as any fuel composed of 85% alcohols regardless of the type.

Corporate Average Fuel Economy (CAFE) calculations. CAFE sets minimum standards for automobile manufacturers to meet average vehicle efficiency for all vehicles they manufacture. PL-100-494 provides a significant regulatory benefit for the production of alternative-fueled vehicles.

Gasohol is a special case for energy security and is viewed as an extender of gasoline rather than as a substitute for gasoline.

Shale Oil

A small group of Members of Congress continue to have high hopes for shale oil. While this is still a hydrocarbon fuel, it is a true alternative since it is not extracted from crude oil. The sheer size of the domestic oil shale resource base is too large to ignore.

Unocal operates the only commercial domestic oil shale extraction facility in western Colorado. After nearly a decade of construction and development, the facility is on the verge of commercial profitability. Even the most ardent proponents recognize that oil shale will need a significant rise in the price of crude oil and continued preferential tax treatment before a second facility is considered.

The Clean Air Perspective

The second perspective views alternative fuels from the standpoint of improving air quality. This perspective considers alternative fuels as any alternative to traditional gasoline and diesel fuel which improves air quality even if the alternative is a crude oil derivative.

This perspective is contained in the Clean Air Act Amendments (H.R. 3030/S.1490) which have recently passed both the House and Senate. The differences between the two bills are currently being considered by a House-Senate Conference Committee.

These bills are comprehensive proposals that address broad aspects of air quality, including industrial sources of smog, air toxics,

and acid rain. Title II of both these bills is known as Mobile Source Controls and contains provisions related to alternative fuels.

Both the House and Senate versions rely heavily on reformulating traditional gasoline. Reformulated gasoline is simply a change from the traditional blending components used to make gasoline. The changes are intended to improve the overall emissions characteristics resulting from the combustion of the fuel in internal combustion engines. Reformulated gasoline will still be a crude oil-derived fuel, although it is likely to contain a low percent of oxygen in the form of alcohols or ethers.² Reformulated gasoline is considered to be an alternative fuel because it is a substitute for traditional gasoline.³

While some companies (ARCO with EC1, Shell, Conoco and Diamond Shamrock) have started selling a "reformulated" gasoline, their product may not be the "reformulation" required by the Clean Air Act Amendments.

The Senate-passed version of the Clean Air Act Amendments contains a provision which sets specifications for all gasoline, not just reformulated gasoline, sold in "severe" or "extreme" non-attainment areas as defined in the Clean Air Act. The Senate version gives the Administrator one year to set specifications for reformulated gasoline to achieve:

- o a maximum aromatic hydrocarbon volume of 30% on January 1, 1992, 28% on January 1, 1994, and 25% on January 1, 1996.
- o the lowest benzene content possible without additional capital investment, but not higher than 1%.
- o a 15% reduction in ozone-forming volatile organic compounds with no increase in NO_x emissions during high ozone seasons as defined by the Administrator of the EPA for evaporative

² Strictly speaking, the term hydrocarbon refers to chemical compounds that contain only the elements hydrogen and carbon. Alcohols and ethers which are composed of oxygen in addition to hydrogen and oxygen are not in the strict sense hydrocarbons.

³ The subject of reformulated gasoline is reviewed in detail in a General Accounting Office Report # GAO/RCED-90-153. Other than this report, there is very little documentation (as opposed to rhetoric) on reformulated gasoline as envisioned in the Clean Air Act Amendments.

emissions.

- o an oxygen content of 2% or greater on Jan 1, 1992, 2.5% or Jan 1, 1993 and 2.7% on Jan 1, 1994 unless a higher content is otherwise specified.

Additionally, the Senate bill requires that on October 1, 1991 all motor gasoline used in any carbon monoxide non-attainment area between October and March must contain 3.1% oxygen.

The effect of these oxygen requirements will be to ensure that alcohols (most likely ethanol) and ethers (MTBE - Methyl Tertiary Butyl Ether and ETBE - Ethyl Tertiary Butyl Ether) are blended with gasoline.

The Senate bill also defines a term "clean alternative fuel" which includes methanol (M-100), methanol-gasoline blends (M-85), ethanol, ethanol-gasoline blends, liquified petroleum gases (LPG), natural gas, electricity and reformulated gasoline for use in certain fleet vehicles. The difference in this reformulated gasoline is that it may not be capable of being used in conventional vehicles. It may be suitable for use only in vehicles specially designed and built for compatibility. This reformulated gasoline may have a different formula than the reformulated gasoline previously discussed in the Senate bill.

The House-passed bill had similar but not identical provisions. The House bill requires the sale of reformulated gasoline in the nine smoggiest United States cities starting in 1994. It also requires that all gasoline sold in the 44 cities with high carbon monoxide content have a minimum oxygen content. The House bill would allow alternative formulations if the emission reductions were equal or greater than those of the specified reference fuel.

Despite the fact that the concept of reformulating gasoline was first proposed by the oil industry, they are not entirely enthralled with these specified gasoline reformulations. The industry lobbied hard against these fuels.⁴

Predictions concerning legislation are always dangerous. The Congressional Quarterly (CQ) on May 26, 1990 wrote "Despite

⁴ Attachments to this paper demonstrate the seriousness and emotion the auto and oil industry attach to some of the proposal.

lingering veto threat and a lengthy conference, there is little doubt about eventual enactment (of the Clean Air bill)." CQ is usually correct in such assessments.

The Farm Policy Perspective

The increased use of ethanol and ETBE (since ETBE is derived from ethanol and is now eligible for the same blender tax credit) will have a significant effect on the Farm Program. Currently, ethanol blends account for approximately 8% of domestic sales of gasoline fuels. This requires over 800 million gallons of ethanol.

Two facts are significant when considering ethanol use.

- Most fuel ethanol is made from corn with approximately 4 to 5 % of corn production going for this purpose.
- Gasoline-ethanol blends with at least 10% ethanol are currently exempt from 6 cents of the 9 cents per gallon federal excise tax on motor fuels⁵ which equates to a 60 cents per gallon benefit for each gallon of ethanol which is blended.

These facts lead to conflicting conclusions. The General Accounting Office (GAO) was requested by the Chairman of the Subcommittee on Energy and Power to use economic modeling to analyze the effect of increased ethanol use. GAO took as their base case an increase in fuel ethanol use from the current 850 million gallons per year level to 2.2 billion gallons per year by 1997. This increase is distinctly possible under the previously mentioned Senate requirement of 2.7% oxygen for all gasoline sold in non-attainment areas. The GAO predicted a 12 cent per bushel increase in corn prices and an associated decrease in federal farm support outlays of \$900 million dollars per year as a result.

Their model also predicted that lost revenue to the highway trust fund would increase by \$440 million per year. Current loss of revenue is approximately \$450 million per year. These figures certainly suggest why there is strong support for increased

⁵ An equivalent 60 cent per gallon federal ethanol blenders income tax credit is also available in lieu of the excise tax exemption. A recent IRS ruling extended the blenders tax credit to ETBE.

ethanol use by Members from the Corn Belt States. Even if their loss to the highway trust fund is considered, increased ethanol use offers a large positive federal budget benefit and improved farm prices.

Unfortunately, other effects are not all positive. Naturally, the highway lobby is distressed by the potential for continued losses from the highway trust fund. Likewise, not all sectors of the farm community benefit. GAO predicts that soybean producers would experience lower prices as by-products from ethanol production compete in the animal feed market.⁶ Consumers would also be faced by slightly higher food costs. Nonetheless, the possibility of contributing to clean air improvements, reducing farm subsidies, and improving the nation's energy security is too attractive a policy to ignore.

The Future for Alternative Fuels

There is another Congressional perspective on alternative fuels which looks well into the twenty-first century. This perspective focuses on the ultra clean alternatives that may supplant today's current fuels and the near term alternatives of alcohols and natural gas.

Hydrogen and electricity are viewed as the alternatives for the future. The exact time table for their use is not clear. Both these fuels have an advantage in that they are totally non-polluting from an air quality standpoint when used as a vehicle fuel. When combusted in vehicles, these fuels produce no carbon dioxide which is particularly valuable as concern for and evidence of the Green House effect continues to mount.

Proponents of these fuels recognize their limitations including the fact that both electricity and hydrogen are not naturally occurring. Both require energy for their basic production and, unless this energy is from nuclear power, these fuels do not offer any Green House effect benefit. Nonetheless, many individuals

⁶ The preliminary results of the GAO study were presented to the House Ways and Means Committee on February 1, 1990. The final report to the Chairman of the House Subcommittee on Energy and Power is expected this summer.

view these fuels as the only suitable long term transportation fuel.

Conclusion

Alternative fuels have a high level of support in the Congress. Rationale for this support varies from a desire to improve United States energy security, to a need to improve air quality, increased use of ethanol as a farm policy, deficit reduction strategy, and a Green House gas strategy.

While all these views have a common denominator, they are not entirely compatible. The nation does not have the resources to support a full scale developmental effort for all alternatives, leading to the desire to pick the winners at the start or set performance standards.

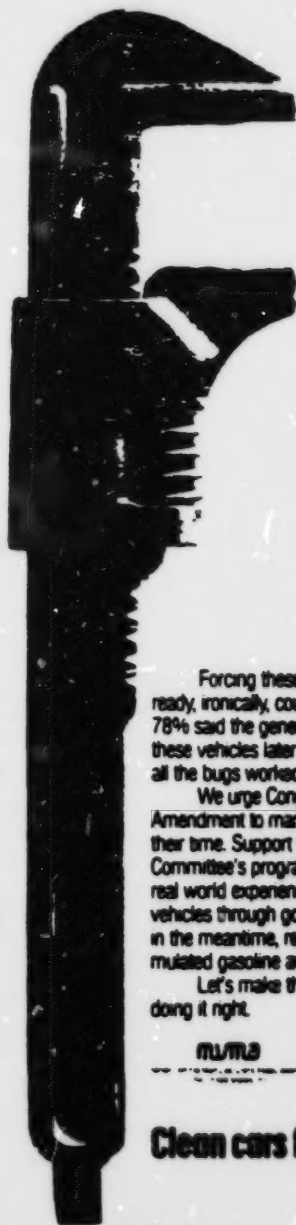
Picking the preferred alternative fuel is fraught with problems including the ability for policy makers to choose the correct, best fuel or fuels. Setting performance standards, while conceptually pleasing from a free market perspective, may launch a detrimental competition between several attractive alternatives.

Congress is currently dealing with this conundrum in the conference on the Clean Air Act Amendments. A compromise is necessary and inevitable. Reformulated gasoline will probably end up as the near alternative fuel of choice. Alcohols and natural gas are likely to receive incentives designed to make them viable fuels in the early part of the next century. Hydrogen and electricity will have to wait for technology improvements before they pass from the laboratory to commercial use.

The Clean Air Act Amendments currently being considered will set United States transportation energy policy for the next two or three decades. The importance of decisions being made this summer in Washington cannot be overlooked.

Congress: Don't throw a monkey wrench into clean car development.

Oppose the Waxman/Lewis Amendment.



We all want cleaner air—but we need the right tools to do the job.

Automakers are working hard to develop vehicles that promise cleaner air. Their goal is to design and produce alternative fuel vehicles which are affordable and can perform as well as—if not better than—cars on the road today.

But there's a lot of work to be done to find the right clean fuels—such as methanol, ethanol, natural gas, liquefied petroleum gas or electricity—and engineer the right clean fuel vehicles to meet that goal.

And that's just the beginning. Consumer concerns need to be resolved about the cost and availability of alternative fuels, the price and reliability of these vehicles and the fact that they can't drive as far on a tankful of alternative fuel as gasoline vehicles.

Yet, some in Congress want to mandate the production of alternative fuel vehicles for the general public by the mid-1990's.

That could throw a monkey wrench into the whole future of clean fuel vehicles.

Forcing these vehicles to market before they're ready, ironically, could kill them forever. In a recent poll, 78% said the general public would be afraid to buy these vehicles later on if the early models didn't have all the bugs worked out.

We urge Congress to oppose the Waxman/Lewis Amendment to mandate alternative fuel vehicles before their time. Support the House Energy and Commerce Committee's program which provides several years of real world experience by phasing-in alternative fuel vehicles through government and private fleets, and, in the meantime, requires making low polluting, reformulated gasoline available for the general public.

Let's make the alternative fuel program work by doing it right.

NUMA

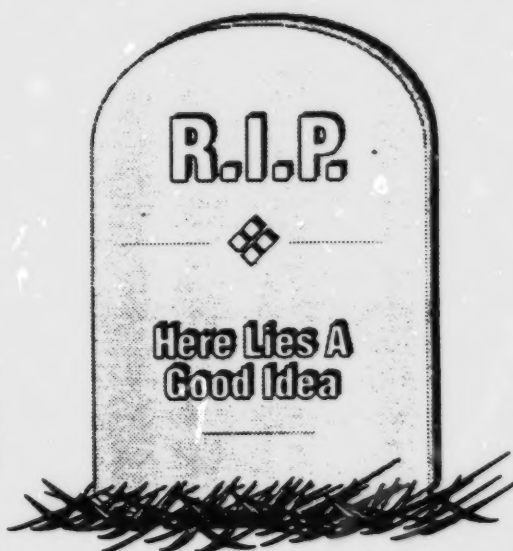


AIAA

Clean cars for a clean tomorrow.

Congress: Don't Kill the Clean Car!

Oppose Waxman/Lewis Amendment



Vehicles fueled by gasoline substitutes — methanol, ethanol, natural gas and electricity — offer cleaner air and less reliance on foreign oil. That's a good idea.

But the Waxman/Lewis Amendment to the House clean air bill would move too far too fast, by forcing the sale of millions of these alternative fuel vehicles.

That's not a good idea.

Why? Because consumers are reluctant to buy these vehicles. They said so, in a recent poll of residents of six of the many cities where these vehicles would have to be sold (Baltimore, Chicago, Houston, Milwaukee, New York and Philadelphia):

- 83% said drawbacks like refueling difficulties, poor cold-weather starting and low resale value would make them reluctant to buy the vehicles.
- 72% said they wouldn't buy them if they cost more than regular cars.
- 83% said that government and large businesses should test alternative fuel vehicles in their own fleets first.
- 78% believe that if alternative fuel vehicles are sold

widely before the "bugs" are worked out people will become hesitant to buy them in the future.

And 56% said they would buy one IF the "bugs" were worked out first. That's good

news for the future of the clean car. The bad news is by mandating production of alternative fuel vehicles before they're ready, Congress could kill the very technology it wants to promote.

House members should oppose the Waxman/Lewis Amendment to mandate the production of alternative fuel vehicles before their time, and support the Energy and Commerce Committee's program to provide real-world experience with them in fleets and promote the use of low-polluting reformulated gasoline for the general public.

Let's make the alternative fuel program work by doing it right.

mvma

Motor Vehicle Manufacturers Association
of the United States, Inc.

Clean cars for a clean tomorrow.

"An Environmental Frankenstein..."



We want cleaner air. So do all Americans. But "Government Gas" is no answer. Congress should set tough toxic and smog reduction goals for fuels and we'll meet them. That's a challenge we're eager to accept.

However, some politicians in Washington want to force Americans to use "Government Gas," their own specific chemical formula for gasoline intended to vastly increase the use of ethanol as an ingredient. They say it'll clean the air, but the news media don't believe them either.

Newspapers as diverse as the *Chicago Tribune* and *The Birmingham Post-Herald* have criticized the clean air impact of such a "Government Gas" proposal. Little Rock's *Arkansas Democrat* warned that the measure "would worsen the worst of the pollutants." The *Detroit News* called the whole idea "an environmental Frankenstein."

The effort to create "Government Gas" is not about pollution, but about politics — a billion-dollar-a-year subsidy that several newspapers called "a classic slice of political pork." It would be another huge subsidy to what *The New York Times* called the "High-Octane Ethanol Lobby."

The *Chicago Tribune* says, "Congress should set tough pollution reduction goals, and let the petroleum chemists and auto engineers find a way to meet them."

We agree. If you do, too, contact your Congressman today to reject the "Government Gas" amendment to the Clean Air Act.

AP American Petroleum Institute
1220 L Street, NW
Washington, D.C. 20005
(202) 682-8000

It Won't Cure The Smog Problem. It Will Cost You More. It Will Cut Auto Efficiency.



So Why Let Politicians Write The Chemical Formula for Gasoline?

Politicians in Washington are writing a specific gasoline formula for use in urban areas where about one-third of American motorists live. Motorists will have to buy "Government Gas." They will have no choice. Yet, no testing has been done to show "Government Gas" is less polluting, more efficient or affordable.

According to the Environmental Protection Agency, "Ozone [smog] continues to be the most pervasive ambient air pollution problem in the U.S." California's Sierra Research, Inc., a leading environmental analysis firm, says the "Government Gas" formula will increase emissions of hydrocarbons and nitrogen oxides — the two principal ingredients of smog — and "this would be expected to lead to increases in ambient ozone levels." Politicians would "solve" the nitrogen oxides problem by simply stating no increase would be allowed — even though such an edict defies science!

All of us want cleaner air. Automakers and oil companies are running thousands of tests on cars with 25 different fuels in search of the best clean-burning gasoline. Answers are just months away.

But politicians are rushing to impose a single formula designed to dramatically increase the use of ethanol. Sierra Research says motorists will be "paying more for dirtier air." The last thing taxpayers need is a political formula that benefits the ethanol lobby with a billion dollar a year subsidy.

We want to make the air cleaner. We believe Congress should set a tough, mandatory pollution reduction goal and then let scientists make fuels that will meet the goal at the least possible cost to consumers.

If you agree, please ask your U.S. Representative to reject "Government Gas" amendments to the Clean Air Act.

♣ American Petroleum Institute 1220 L Street, NW, Washington, D.C. 20005 (202) 682-8000

ATMOSPHERIC CHANGE AND SUSTAINABLE DEVELOPMENT

Possible Implications for Alternative Fuels

**Presentation to 1990 Windsor
Workshop on Alternative Fuels**

**J.D. McTaggart-Cowan
Office of Environmental Affairs
Energy, Mines and Resources Canada**

June 12, 1990

PUBLIC CONCERNS

91 percent of 10 Canadians are somewhat or very concerned about the quality of the environment

[Decimal, Winter 1989]

8 in 10 think clean-up and protection of the environment will contribute significantly to the growth of the economy

[Environmental Monitor, Fall 1988]

7 in 10 Canadians say environmental concerns should have priority over economic growth

[Focus Canada, Summer 1989]

Environmental protection ranks second only to job creation on how Canadians would like to see their tax dollars spent

[Environmental Monitor, Fall 1988]

60 percent believe government should spend more on environmental protection, while only 32 % believe more should be spent on energy development

[Focus Canada, Fall 1988]

Eight in ten Canadians say they are willing to pay extra for increasing government spending on environmental protection

[Environmental Monitor, Fall 1987]

89 percent say they are willing to pay more through higher prices or higher taxes for environmental protection

[Environmental Monitor, Fall 1988]

SUMMARY OF PUBLIC CONCERNS

Heightened awareness of link between environmental pollution and human health and safety

Recognition of relationship between the quality of the environment and continuing prospects for economic growth

Environment consistently given priority over the economy

Strong, consistent indications consumers are willing to pay (but also demand that revenues be used for environmental programs)

CORPORATE ACTION

- | | |
|------------------------|--|
| MONSANTO - | Reduced air emissions
17% in one year |
| UNION CARBIDE - | Reduced air emissions from
industrial gases facilities
by 53% in one year |
| 3M COMPANY - | Plan to reduce emissions
by 90% by 2000 |
| McDONALD'S - | Stopped using CFC's in fast food
packaging |
| CHEVRON - | Reduced hazardous waste
production at oil refineries by 20% |

GENERALLY

**Industry recognizing that it never hurts to re-examine
potential solutions previously considered too expensive**

**"As cost of waste disposal and compliance go up, what
wasn't cost effective before may be now"**

**GLOBAL DIMENSIONS OF
ENVIRONMENTAL ISSUES**

May 1987

**The Report of the Brundtland
Commission:**

"Our Common Future"

June 1988

The Changing Atmosphere Conference

CHRONOLOGY OF INTERNATIONAL AGREEMENTS

International Convention on LRTAP (Geneva, 1979)

Protocol on SO_x emissions (1985)

**Protocol on Substances that Deplete the Ozone Layer
(Montreal, October 1987)**

Protocol on NO_x emissions (October 1988)

Protocol on VOC emissions (under development)

**Proposed Framework Convention on Global Climate
Change (target date June 1992)**

INTERNATIONAL RESPONSE

Mar. 1989 Hague Environmental Summit

May 1989 Francophone Summit

May 1989 IEA Ministerial Meeting

June 1989 OECD Ministerial Meeting

July 1989 Economic Summit

Oct. 1989 Commonwealth Summit

Nov. 1989 Nordwijk Declaration

May 1990 Bergen Ministerial Conference

KEY UPCOMING EVENTS

- | | |
|------------------|---|
| July 1990 | Economic Summit - Houston |
| Aug. 1990 | Intergovernmental Panel on Climate Change (IPCC) - Sweden |
| Nov. 1990 | Second World Climate Conference - Geneva |
| Jan. 1991 | OECD Environment Minister's - Paris |
| June 1992 | United Nations Conference on Environment and Development [ECO-92] - Brazil |

MAJOR ATMOSPHERIC ISSUES

Climate Change

Stratospheric Ozone Depletion

Long Range Transport of Airborne Pollutants

Arctic Haze

Local Air Pollution

Indoor Air Quality

MAJOR ATMOSPHERIC ISSUES

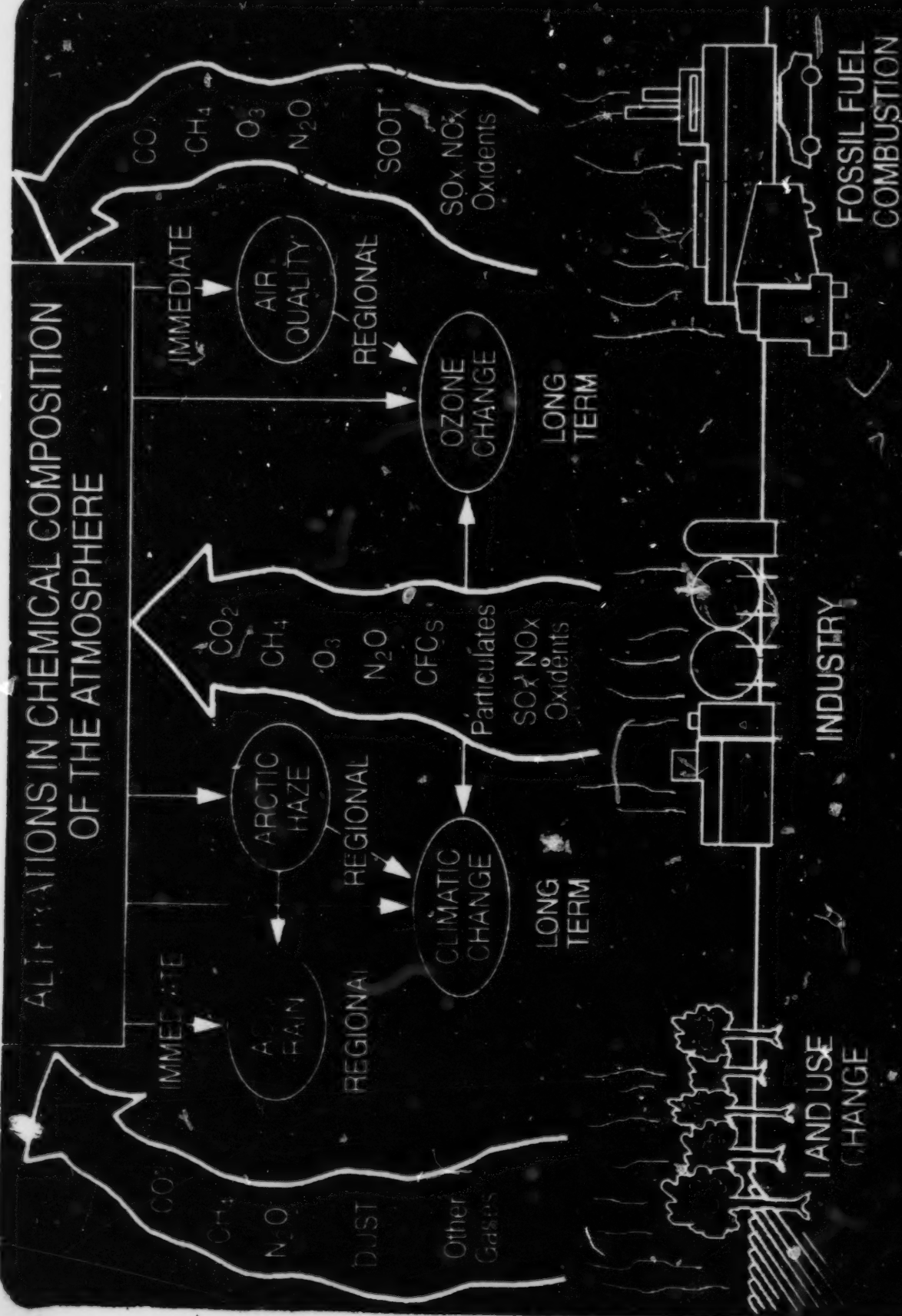
All these major atmospheric issues are related as they arise from alterations in the chemical composition of the atmosphere

There is irrefutable scientific evidence that human activity has changed the chemical composition of the atmosphere

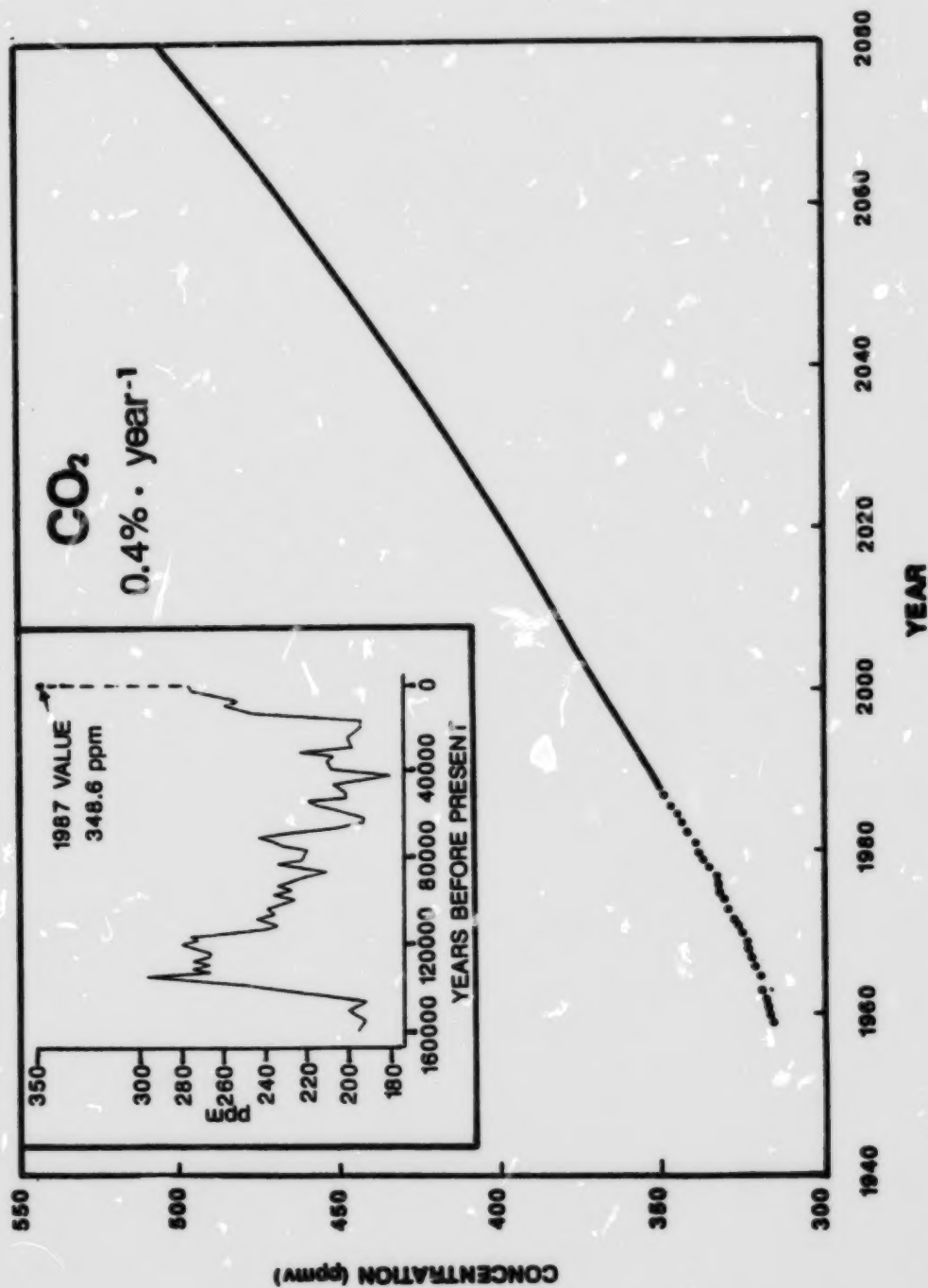
Historical analyses indicate the rate of change is unprecedented in geological time frames

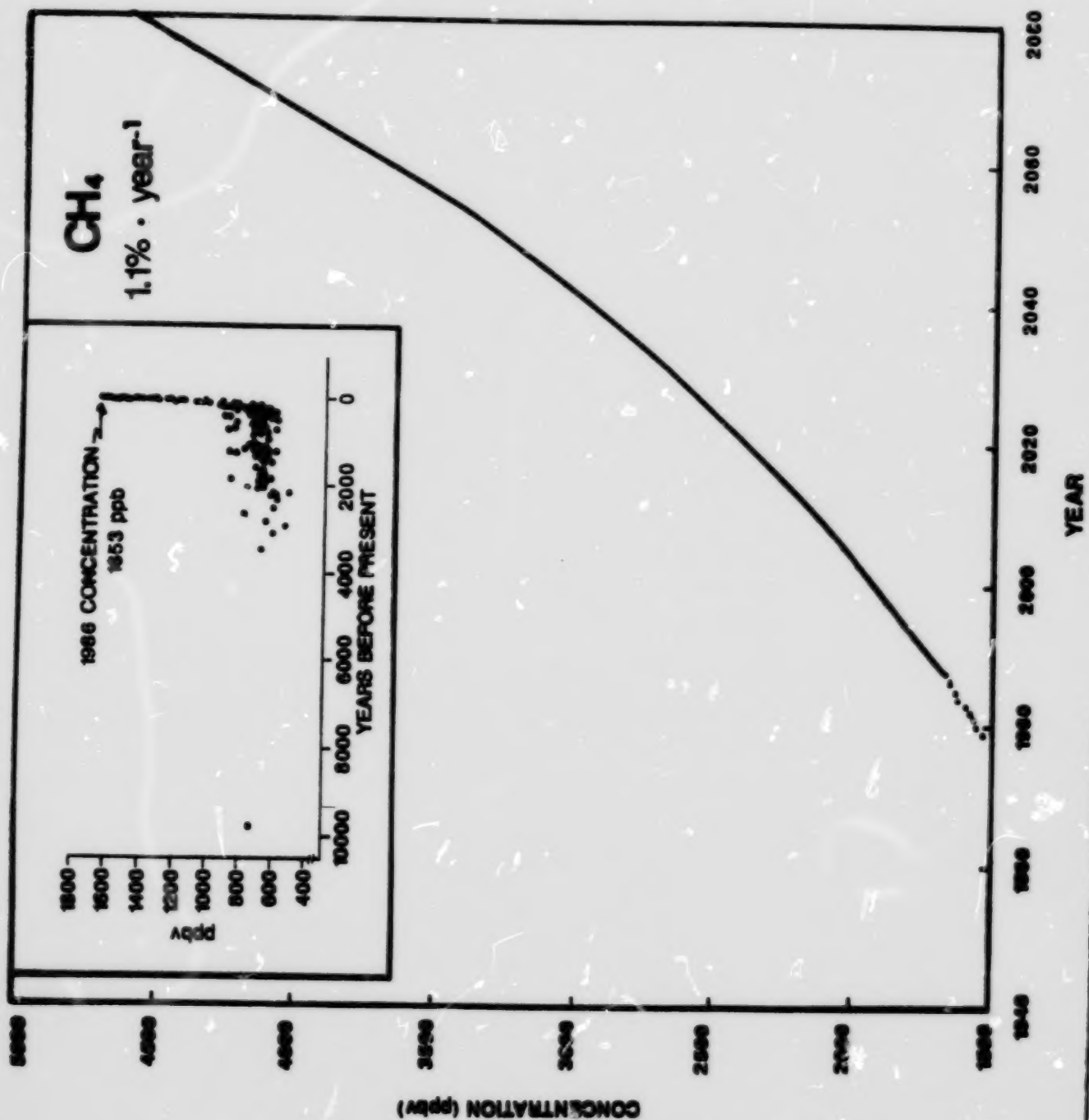
Energy production and consumption play important roles in contributing to environmental stress in each of these areas

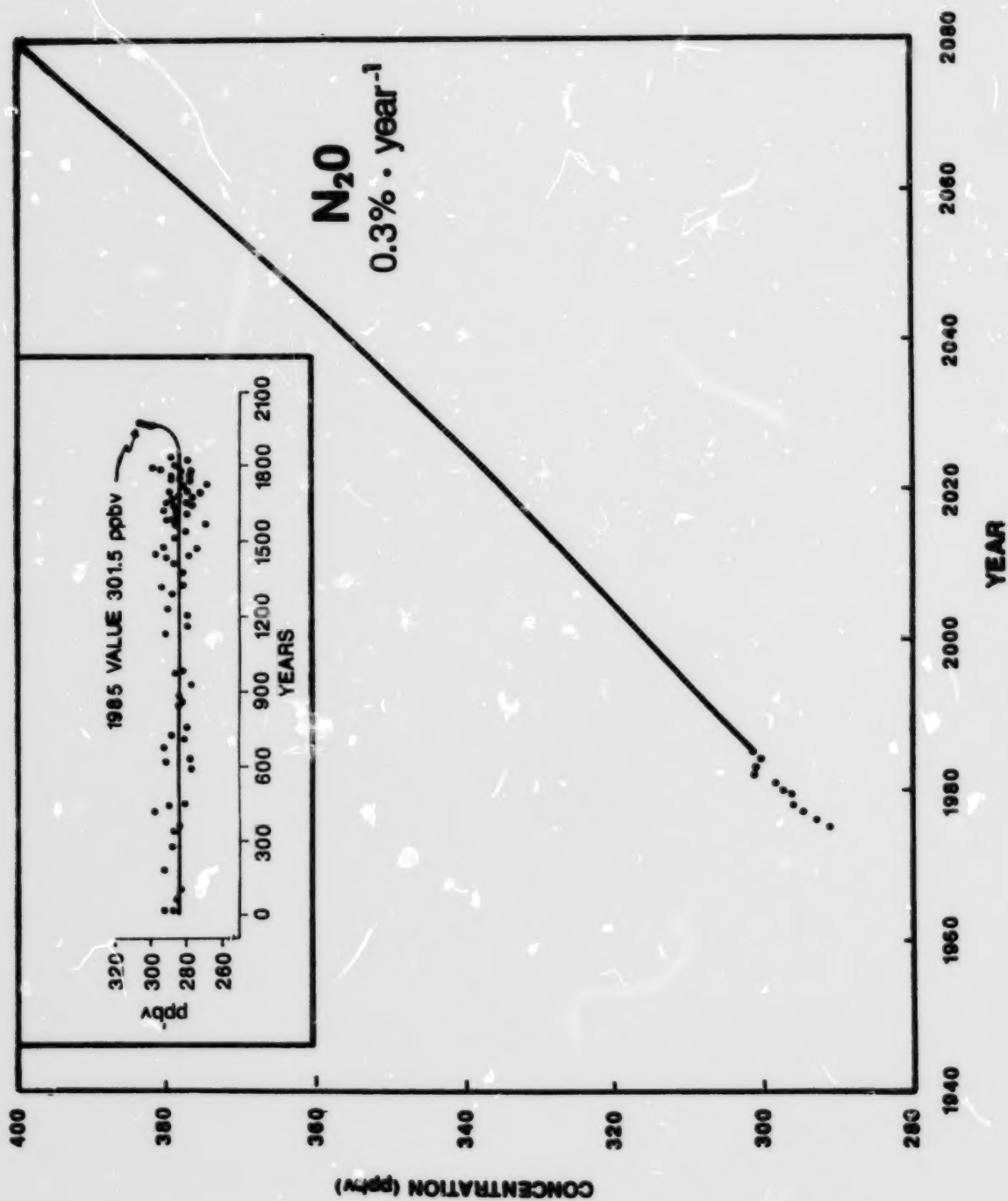
ALTERATIONS IN CHEMICAL COMPOSITION OF THE ATMOSPHERE

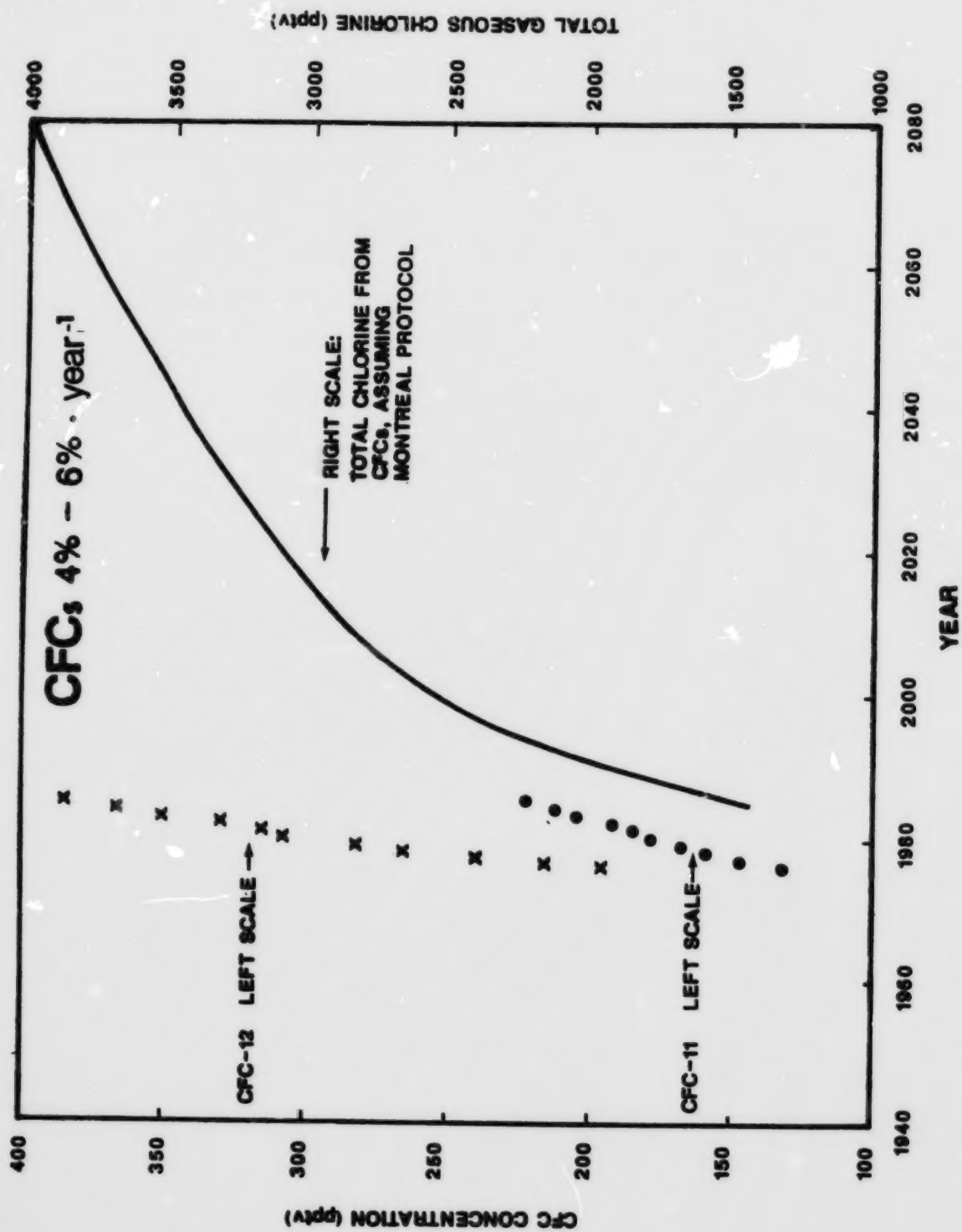


Linkages between Human Activities, Atmospheric Change, and Current Issues









SOURCE GASES

**Undisputed scientific evidence that
atmospheric concentrations of:**

Chlorofluorocarbons (CFC's)

Halons

Methane

Nitrous Oxide

Carbon Dioxide

Are all increasing:

On a global scale

At an unprecedented rate

Due to human activity

GLOBAL ATMOSPHERIC CHANGE - THE FACTS

The state of the environment is changing

Changes are occurring much faster than before

Humans are influencing these changes

**Humans do not understand the global system
enough to make perfect predictions**

Surprises will occur

Humans can control the rate of change

GLOBAL CLIMATE CHANGE

Beginning to emerge as the dominant environmental issue

Scientific community uncertain whether climate change is beginning to occur as yet due to lag effects in natural system

Historical emissions of CO₂ and other greenhouse gases may already have committed the world to some level of global warming

GLOBAL CLIMATE CHANGE - MODEL PREDICTIONS

Global circulation models (GCM's) predict a doubling of CO₂ emissions will:

- **increase average global temperature by 2.8°C to 5.2°C**
- **induce a further rise of 25 to 165 cm in mean sea level**
- **change global precipitation patterns and hence soil moisture**
- **cause greater temperature increases in northern latitudes than global mean**
- **shift growing regions at rates faster than natural species migration**

Uncertainty exists about the likely timing and magnitude of these and other effects

WHAT CAN BE DONE ABOUT CLIMATE CHANGE?

Two fundamentally different policy responses:

DO NOTHING **Deny the scientific evidence and
predictions and wait for conclusive
"proof"**

ACT NOW **Take common sense actions to avoid or
mitigate potential effects**

POLICY ISSUES:

Should Energy/Environment Policy be driven by concerns over CO₂ emissions and the potential for climate change?

Can we afford to continue to address our environmental problems one at a time?

Two possible conceptual approaches:

ENVIRONMENTAL PROTECTION

OR

SUSTAINABLE DEVELOPMENT

ENVIRONMENTAL PROTECTION

(The Present Approach)

- **Focus action on effects rather than sources**
- **Issues considered simply environmental concerns**
- **Each issue dealt with essentially independently**
- **Environment Policy as a limited, add-on field**
- **React & Cure Approach**
- **Regulation most common policy tool**

SUSTAINABLE DEVELOPMENT

- **Focus action on sources of problems**
- **Sources include:**
 - **human activities**
 - **attitudes**
 - **behaviour**
 - **policies (including economic incentives, regulations, codes)**
 - **institutions**
 - **process of decision making**
- **Issues dealt with holistically in linked environment-development framework**
- **Agenda is policy centred**
- **Institutions responsible for policy are held responsible and accountable**

DEVELOPING AN ENVIRONMENTAL POLICY FRAMEWORK

What are we trying to achieve?

**ENVIRONMENTALLY SUSTAINABLE
ECONOMIC DEVELOPMENT (ESED)**

Two components:

Environmental Sustainability

Economic Development

Similar definitions with different wording offered by:

- **BRUNDTLAND COMMISSION**
- **NATIONAL TASK FORCE ON
ENVIRONMENT AND ECONOMY**
- **ENERGY OPTIONS**

DEFINITIONS OF SUSTAINABLE DEVELOPMENT

BRUNDTLAND COMMISSION DEFINITION:

"Sustainable Development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs"

ANOTHER DEFINITION OF ESED:

"Economic development which does not destroy or undermine the basis on which our future development and well being depend"

ECONOMIC DEVELOPMENT

OR

ECONOMIC GROWTH?

ECONOMIC GROWTH

INCREASE QUANTITY

Increasing recognition that economic activity is over-stressing the capacity of the natural environment to absorb wastes

Common property resources of air, land and water are unlikely to be able to continue to absorb the wastes from "sustained economic growth"

ECONOMIC DEVELOPMENT

IMPROVE QUALITY

Increasing awareness of the need for fundamental change in the way we think and do things

Replace "Growth" paradigm with focus on qualitative development

FUNDAMENTAL PRINCIPLES OF SUSTAINABLE DEVELOPMENT

PROCESS PRINCIPLES

Goal Seeking

Systems Oriented

Adaptive

Interactive

SUBSTANTIVE PRINCIPLES

Fulfilment of basic human needs

Maintenance of ecological integrity

Provision for social self-determination

Achievement of equity

ESED - SUGGESTED OPERATIONAL OBJECTIVE:

Maintain and Enhance Environmental Quality

How can we achieve ESED?

Apply specific operational principles —

Employ broad implementation strategies

Devise policy objectives

**Assess acceptability and suitability of policy
instruments**

OPERATIONAL PRINCIPLES FOR ACHIEVING ESED

4 specific principles to guide development activities:

Prudent resource management

Zero discharge

Assimilative capacity

Mitigate impacts (no net loss)

STRATEGIES TO ACHIEVE ESED

ANTICIPATE AND PREVENT

REACT AND CURE

ACCEPT AND MITIGATE/ADAPT

DEVELOPING/IMPLEMENTING ENVIRONMENTALLY APPROPRIATE TECHNOLOGY

Society's collective ability to effectively respond to environmental issues is constrained by available technology

Achieving sustainable development challenges us:

- To find ways to improve existing technology**
- To develop new technology**
- To move technology into the marketplace**
- To transfer appropriate technology on favourable terms to developing countries**

Strategic assessment of what technology can and cannot do for us, specific opportunities, constraints and likely development time frames is urgently required

Increased emphasis is required on the development of technologies for sustainable use of all energy resources, especially renewable sources, including biomass

WHAT ACTIONS MAKE SENSE NOW?

**Rigorous Demonstration of the "4 R's" of
Resource Management:**

REDUCE

RECYCLE

REUSE

RECOVER

**Implement necessary actions to improve the efficiency
of resource use**

**Encourage the substitution of environmentally
preferable materials, processes, and fuels**

**Assist industry in modifying existing processes to
reduce environmental effects**

**Ensure adequate awareness of available and emerging
opportunities for improvement**

Focus available R,D&D resources more strategically

**Emphasize environmental advantages and business
opportunities**

**Encourage industry to look for opportunities, not
constraints!**

WHAT HAVE WE ALREADY LEARNED FROM THIS ISSUE?

Energy, environment & economy are inextricably linked

**Global warming is simply a form of feedback from the
earth's ecological system to the world economic system**

SESSION 3 - HEAVY-DUTY VEHICLES

Co-Chairs: Wendel Goetz, ORTECH International
Rich Bechtold, E.A. Mueller Assoc.

DETROIT DIESEL NATURAL GAS ENGINE DEVELOPMENT STATUS



HOMOGENOUS AUTO-IGNITION TWO-STROKE ENGINE CONCEPT

**GAS AND AIR ARE MIXED BEFORE
TURBOCHARGER COMPRESSOR.**

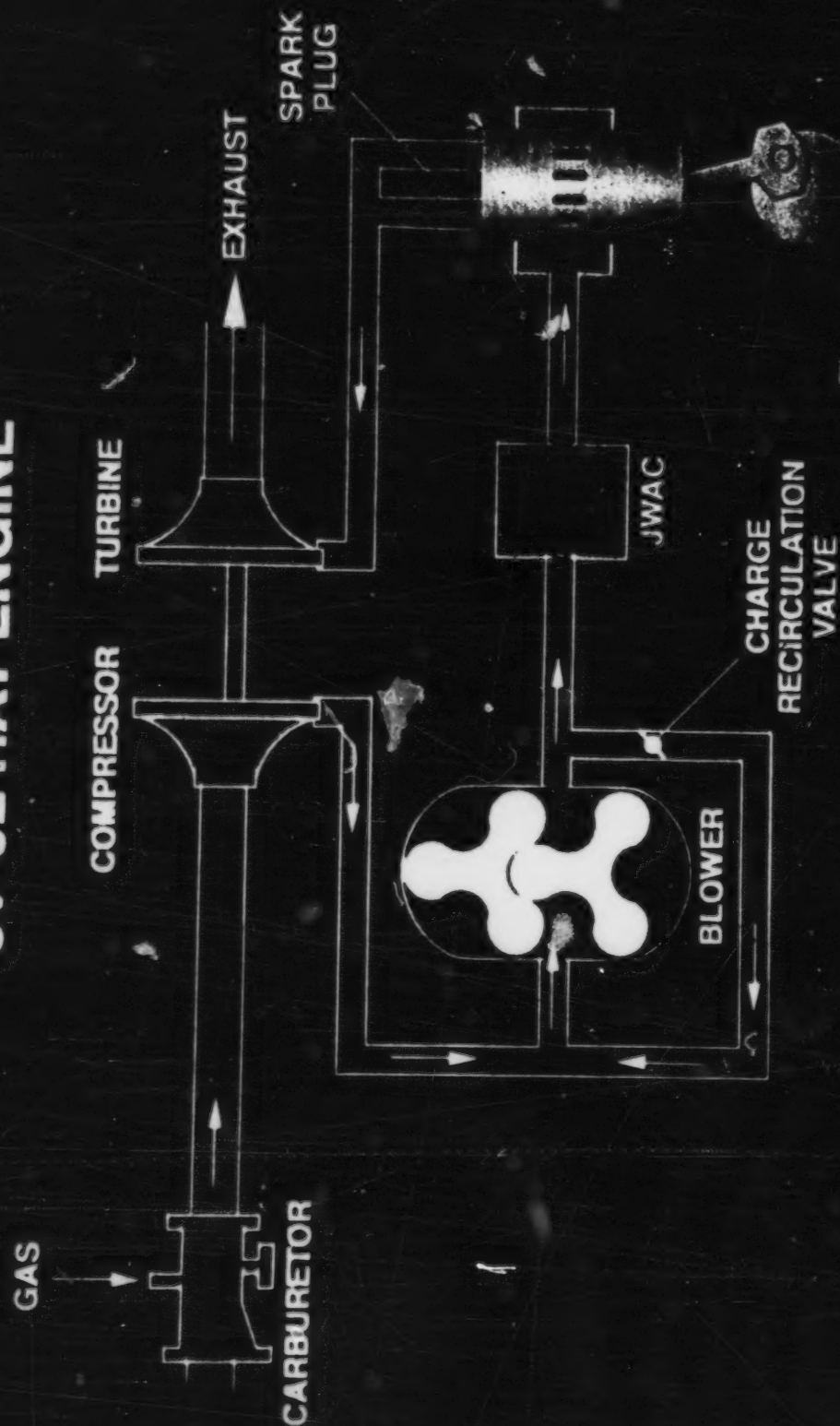
**COMPRESSION OF MIXTURE WITH HOT
RESIDUAL CAUSES IGNITION.**

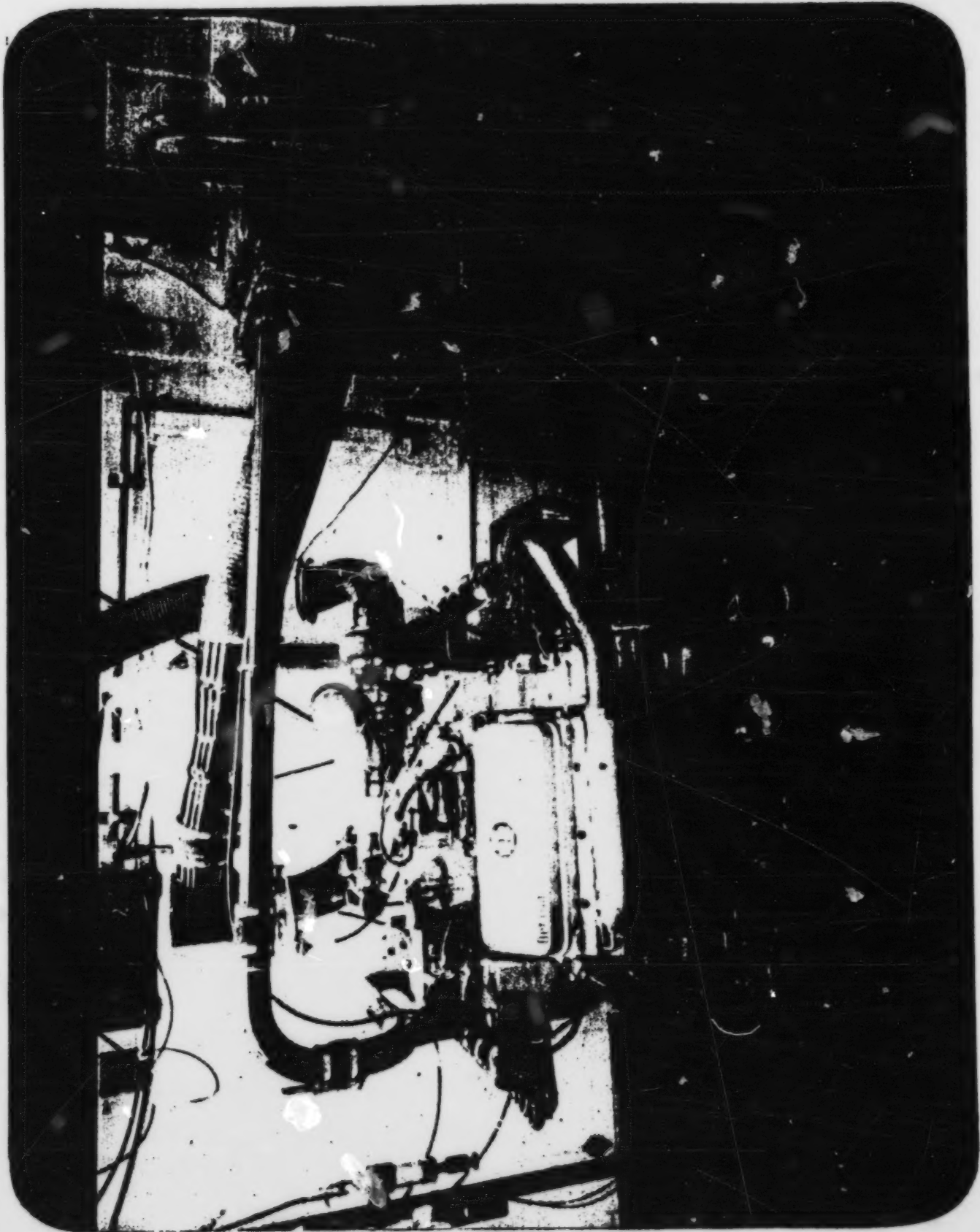
SPARK PLUG USED FOR STARTING AND WARMUP

**FUEL/AIR RATIO AND SCAVENGING
RATIO CONTROL ENGINE OUTPUT
AND COMBUSTION TIMING.**

3333

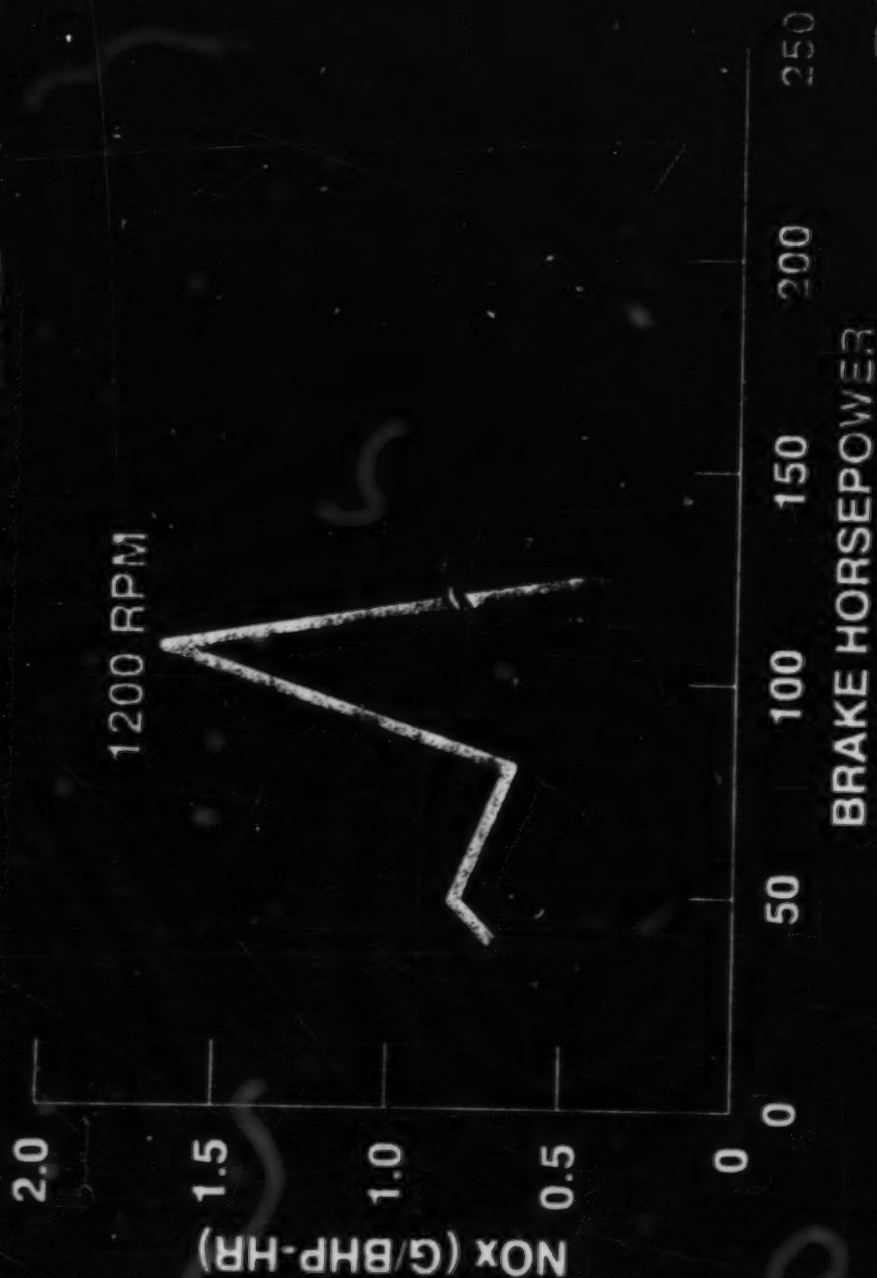
6V-92 HAT ENGINE



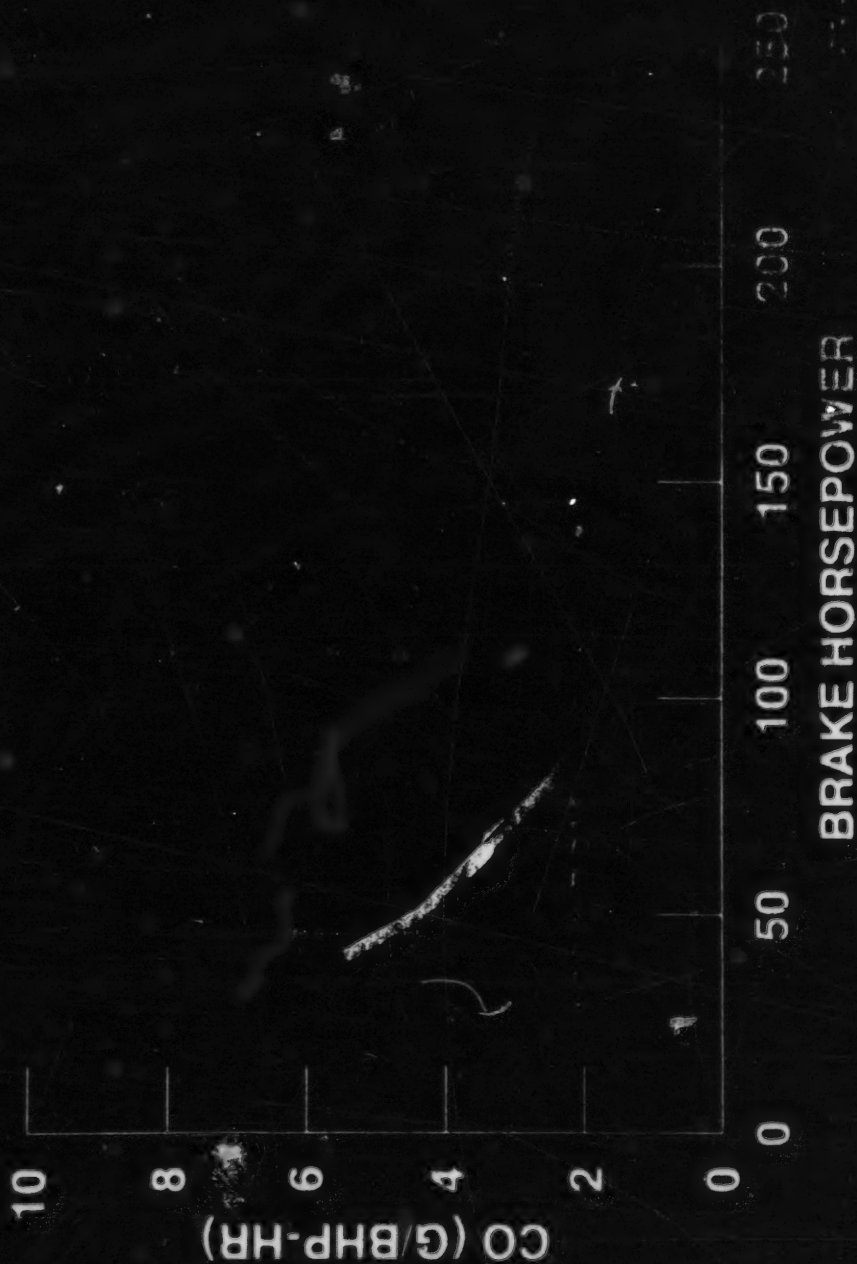


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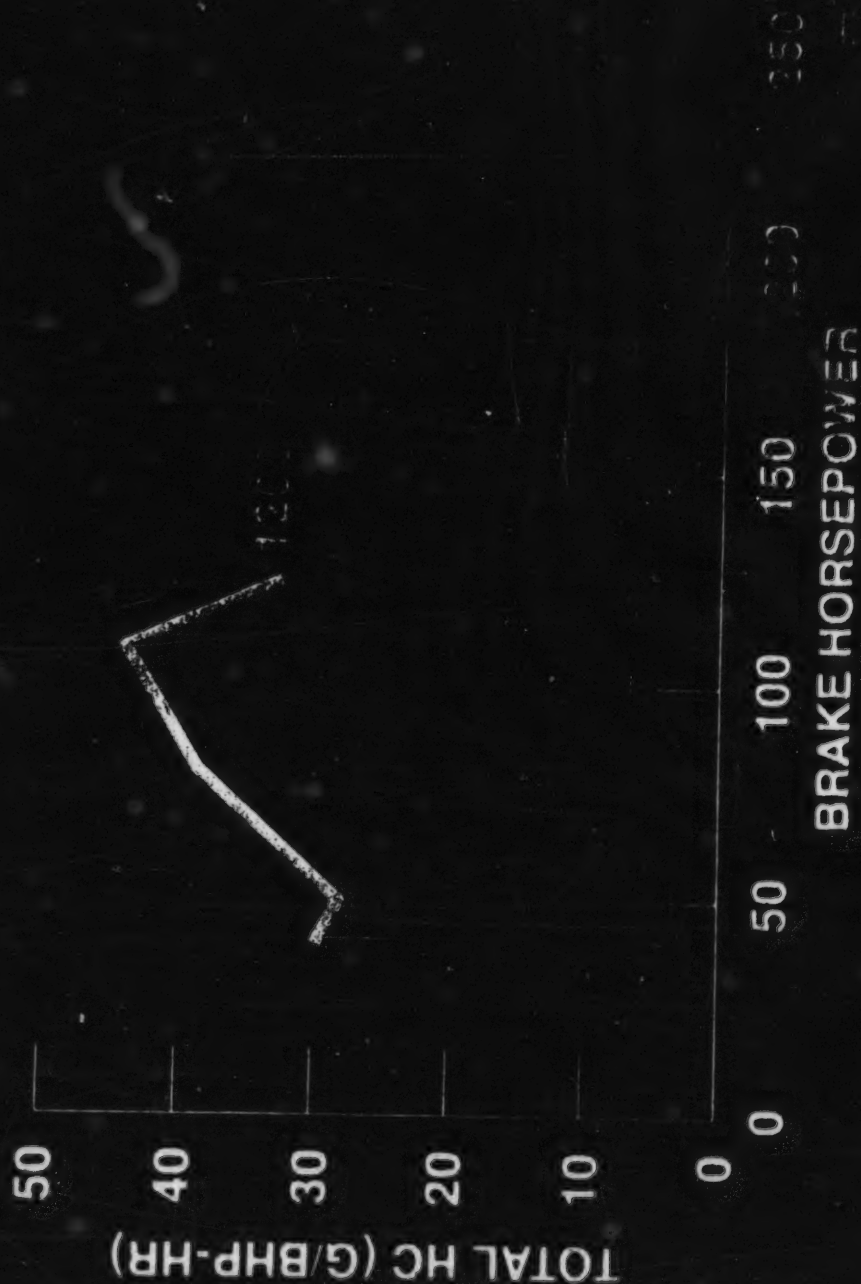
NOx EMISSIONS 6V-92 CNG HAT ENGINE



CO EMISSIONS 6V-92 CNG HAT ENGINE



HC EMISSIONS 6V-92 CNG HAT ENGINE



6V-92 CNG HAT ENGINE OPERATING REGION



ENERGY EFFICIENCY COMPARISON @ 2100 RPM



ENERGY EFFICIENCY COMPARISON @ 1200 RPM



HOMOGENEOUS AUTO-IGNITION TWO-STROKE ENGINE SUMMARY

NOx EMISSIONS ARE VERY LOW.

**FUEL CONSUMPTION IS REASONABLE.
BETTER AT HIGHER SPEEDS.**

MINIMUM OUTPUT LIMITED BY IGNITION.

**MAXIMUM OUTPUT LIMITED BY KNOCK
AND PEAK PRESSURE.**

00000

TWO-STROKE NATURAL GAS ENGINE CONCEPT

DUAL-FUEL

PRECHAMBER SPARK-IGNITION

HOMOGENEOUS AUTO-IGNITION

PRECHAMBER COMPRESSION-IGNITION

DIRECT INJECTION AUTO-IGNITION



IMPORTANT ENGINE CONSIDERATIONS

EMISSION LEVELS

COST

COMPLEXITY - RELIABILITY

DURABILITY

FUEL EFFICIENCY

HEAT REJECTION



TWO-STROKE CNG ENGINE CONCEPTS

	<u>DUAL FUEL</u>	<u>SI PRE-CHAMBER</u>	<u>HAT</u>	<u>DI</u>	<u>CI PRE-CHAMBER</u>
MAIN CHAMBER GAS ADDITION	TIMED VALVE	TIMED VALVE	CARBURATOR	INJECTOR	NONE
PRECHAMBER GAS ADDITION	NONE	CHECK VALVE	NONE	NONE	CHECK VALVE
REQUIRED GAS PRESSURE (psig)	300	300	2	800 OR 3000	5-100
COMPRESSION RATIO	15-17	11-13	17	23	17
IGNITION	DIESEL FUEL	SPARK	COMPRESSION	COMPRESSION	COMPRESSION
STARTING	(ETHER)	SPARK	SPARK	GLOW PLUG	SPARK
LOCATION	ORTECH	ORTECH	DDC	(DDC)	(SWRI)
STATUS	STARTING DEMONSTRATION	BEING DEVELOPED	TERMINATED	AWAITING CONTRACT	AWAITING CONTRACT



INTRODUCTION

**6V-92TA DIESEL PILOT AND S.I. NATURAL GAS
ENGINE DEVELOPMENT**

**ALAN WELCH, RAY SKINNER
ORTECH INTERNATIONAL**

**LLOYD AUSTIN
STEWART AND STEVENSON POWER, INC.**

PARTICIPANTS

GAS RESEARCH INSTITUTE

STEWART AND STEVENSON POWER, INC.

ORTECH INTERNATIONAL

DAI

LUCAS DIESEL SYSTEMS

ERIK KELGARD

DETROIT DIESEL

Background

- DDC 6V-92TA Engines Represents a Large Share of Present North American Bus Engine Fleets.
- Many North American Cities are in Non-compliance with Air Quality Requirements
- Reducing Emissions from Older Rebuilt Engines will Contribute to Improved Air Quality
- Stewart and Stevenson has an Extensive Service Network
- Market for Low Emission Rebuilt Engines (Over Next Five (5) Years or More)
- Potential for OEM Engines

Original Objective

- Natural Gas/Diesel Pilot Ignition Engine Based on the DDC 6V-92TA Engine
- Target Engine for Retrofitting of Older Engines in order to Reduce Visible Smoke

Redefined Objectives

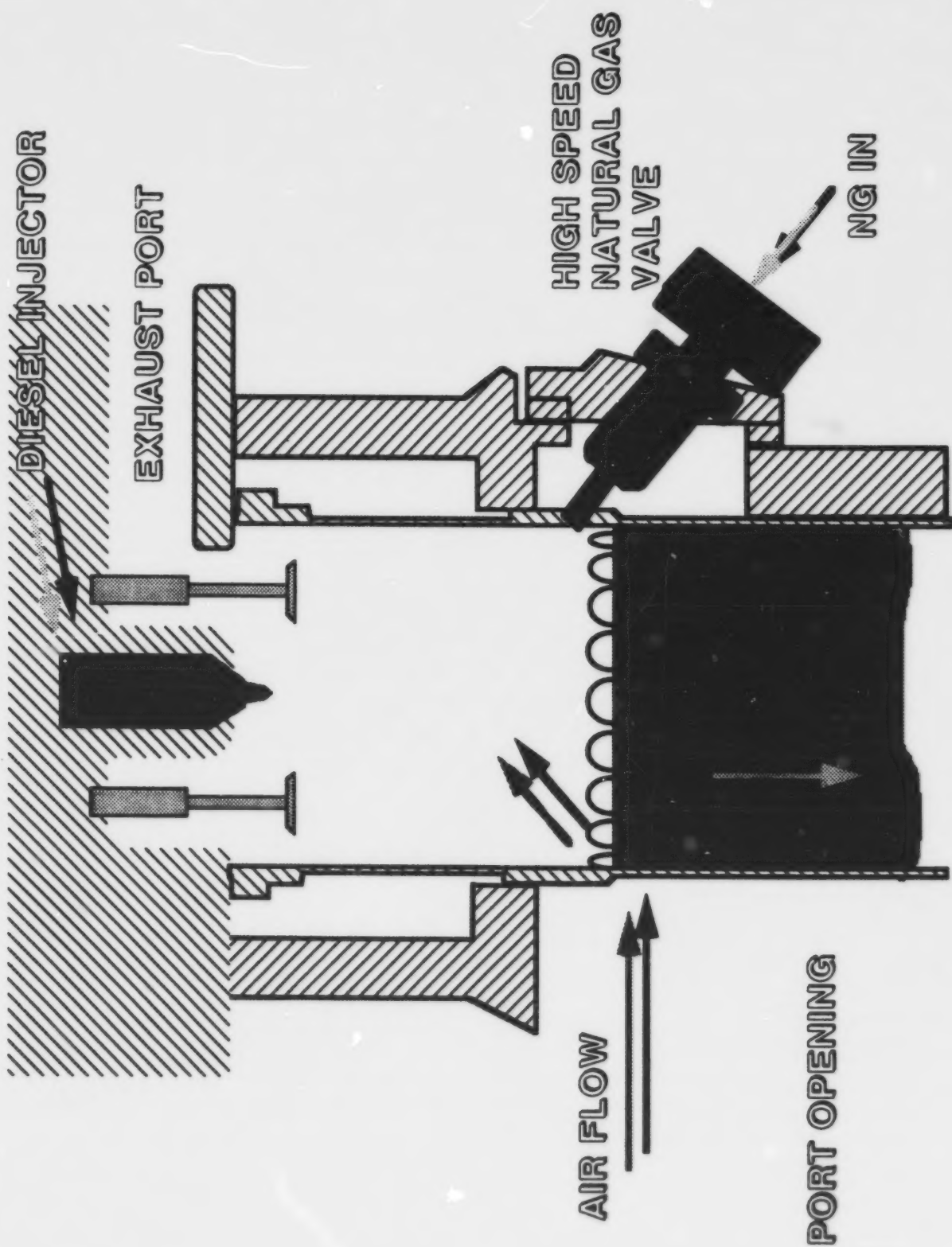
- **Natural Gas Diesel Pilot Ignition Engine (6V-92TA) Utilizing Computer Control and using Timed Port Injection of Natural Gas, Designed to meet the 1991 EPA Emission Standards for Bus Engines.**
- **Parallel Program on Prechamber Spark Ignited 6V-92TA Engine using the same Timed Port Injection System for Natural Gas.**

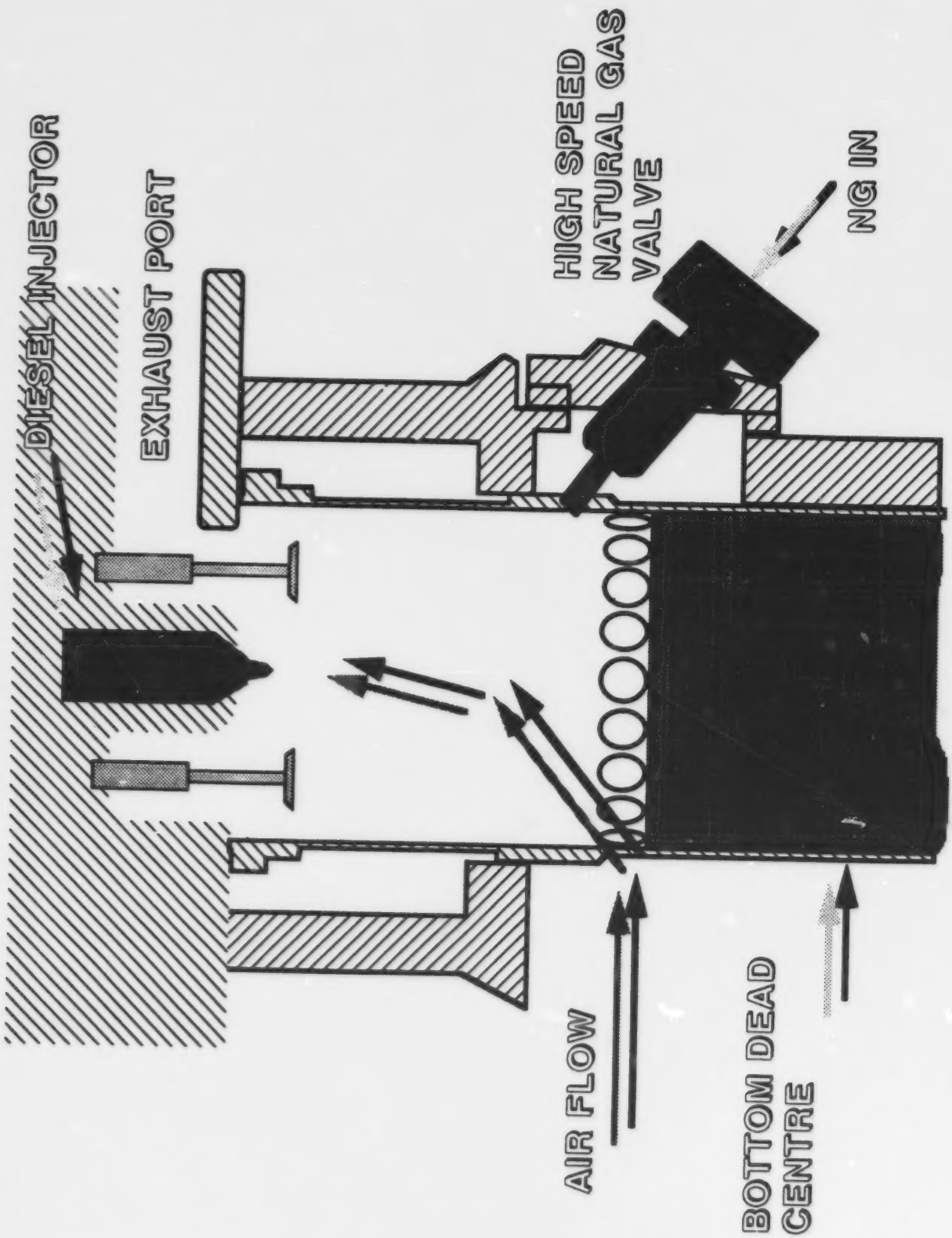
Key Issue

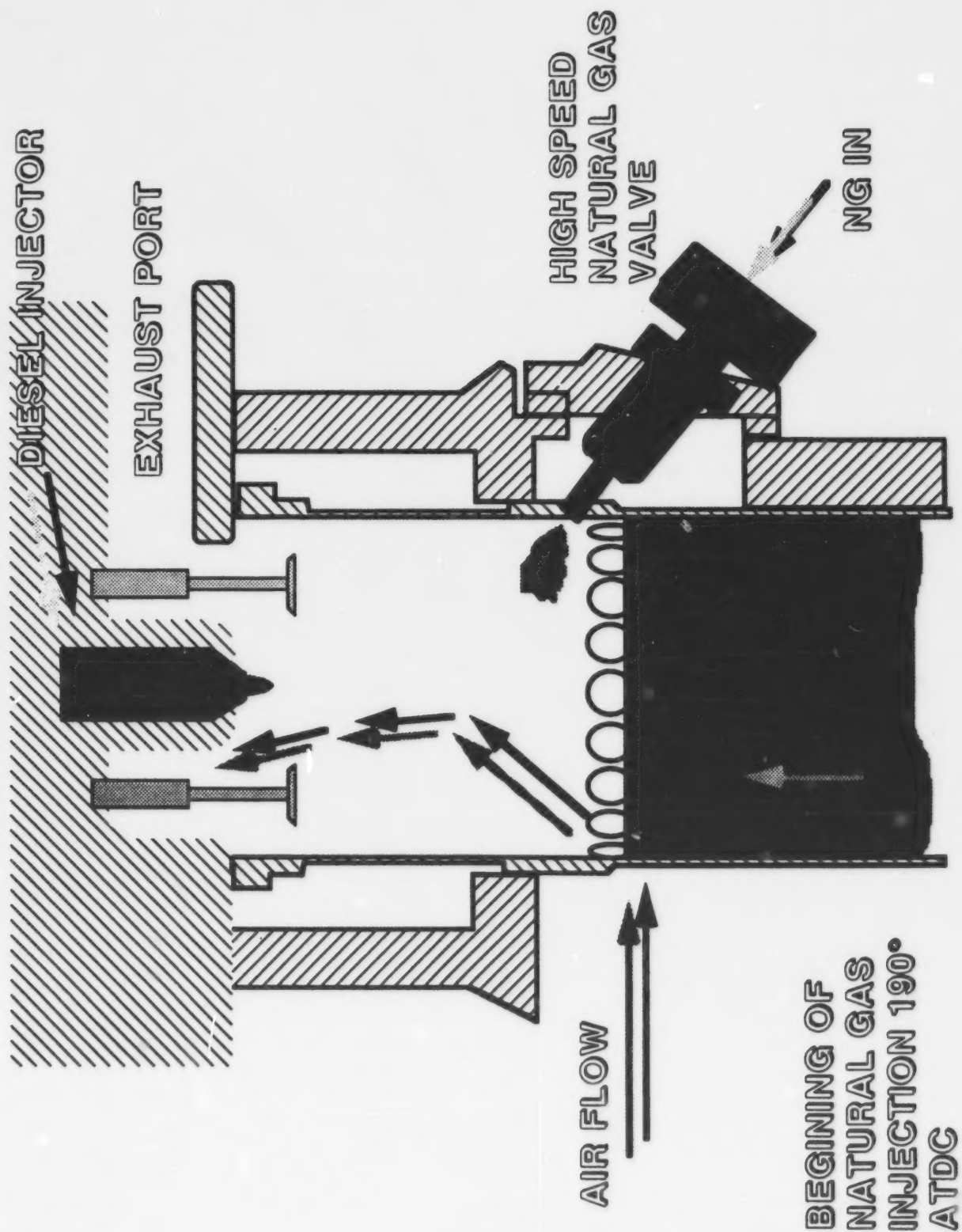
- In a Two-Stroke Diesel Engine, Typically 25% of the Inducted Air Charge is Swept through the Cylinder and out the Exhaust During the Scavenging Process.
- Currently Dual Fuel Natural Gas Two-Stroke Engines induct a Homogeneous NG/Air Charge. Therefore, 25% of the Natural Gas is Lost due to the Scavenging Process.

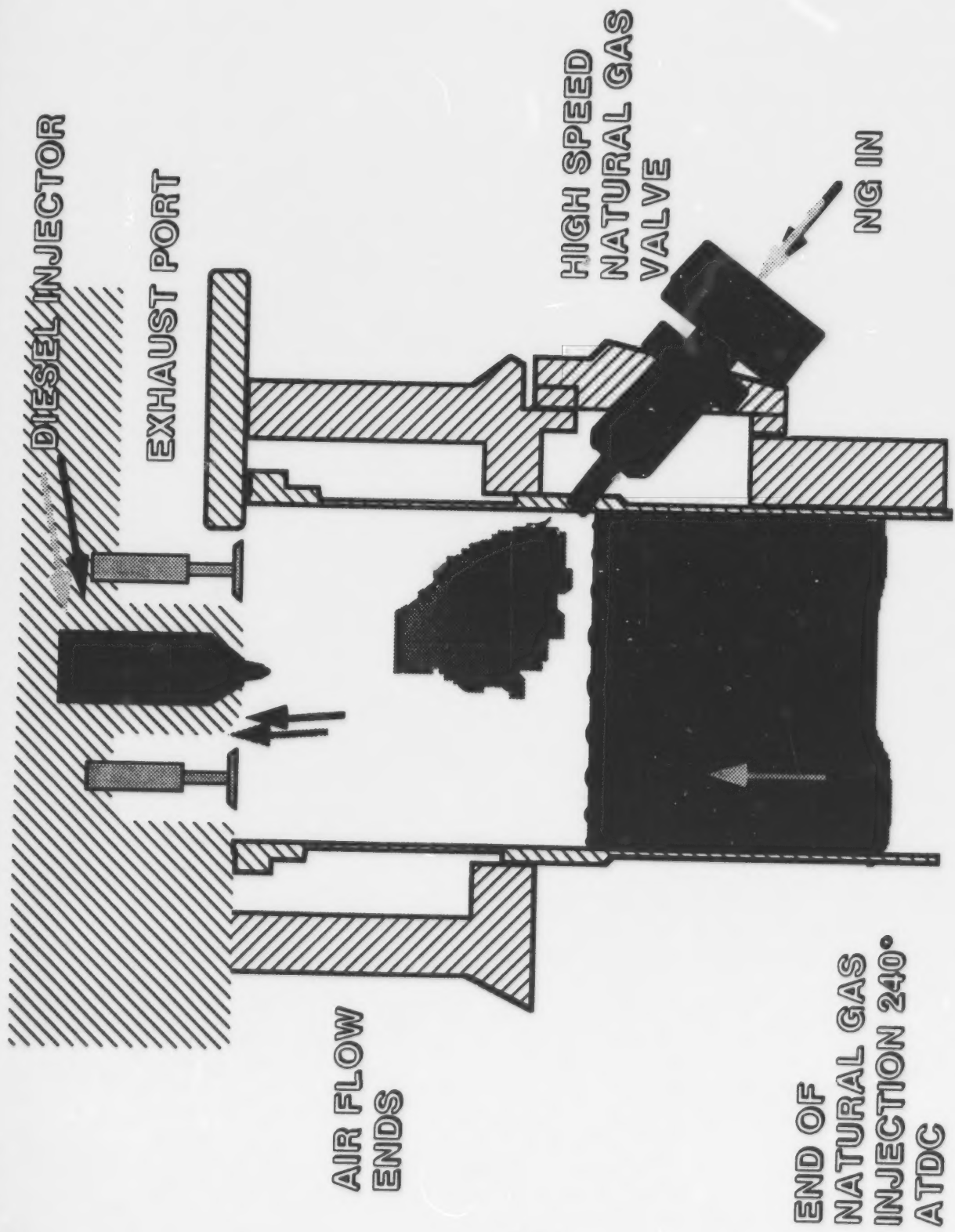
Proposed Solution

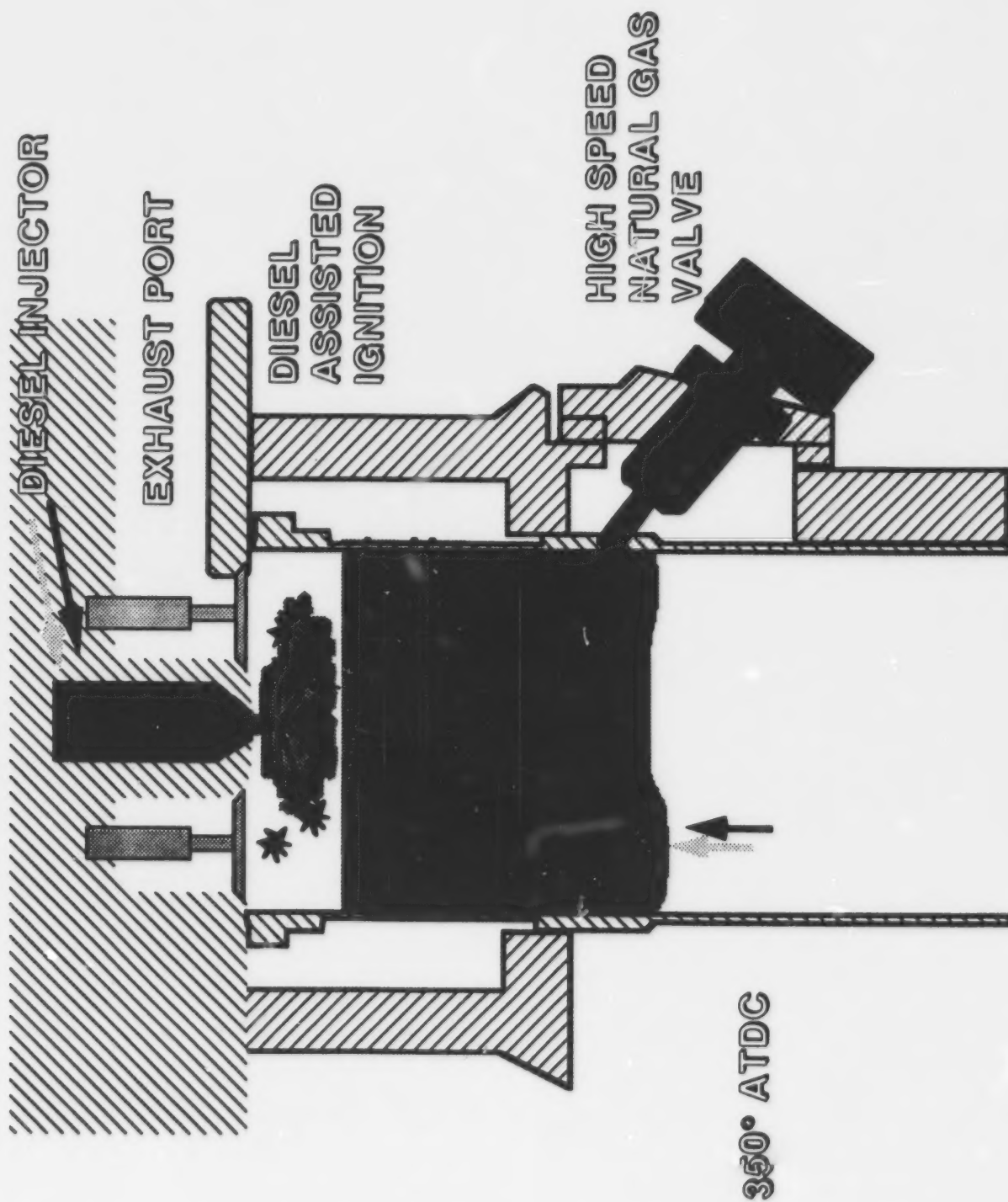
- **Through Timed Injection of Natural Gas in the Second Half of the Scavenging Process, Ideally no Natural Gas will be Lost to the Exhaust.**





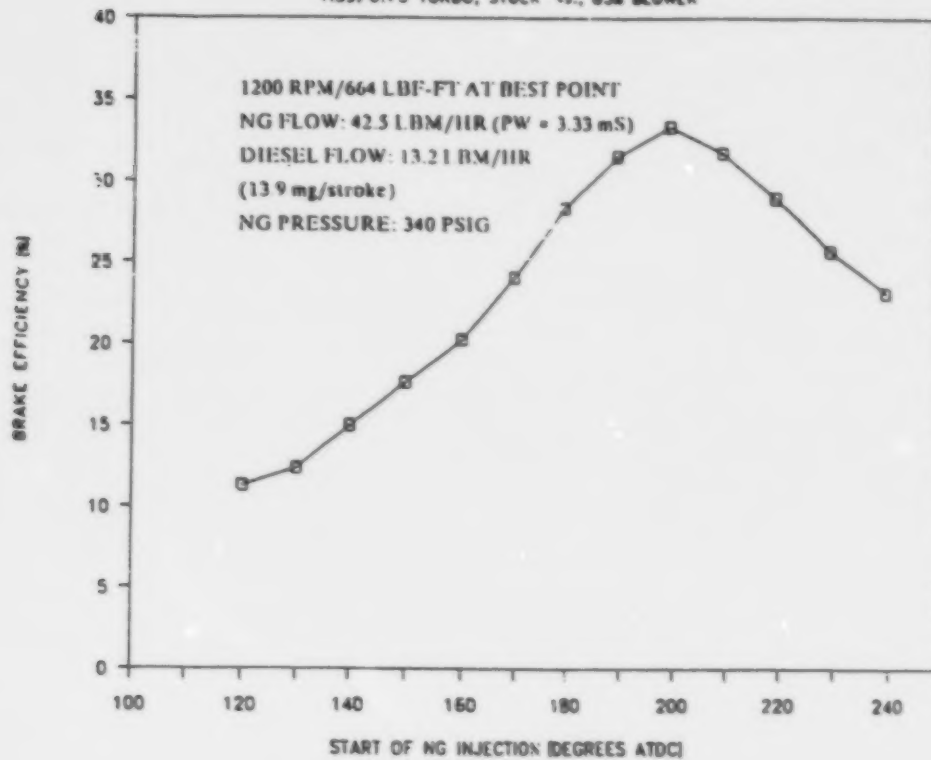






EFFECT OF NG INJ. TIMING ON EFFICIENCY

1.39/0.75 TURBO, STOCK INJ., 83% BLOWER



TECHNICAL APPROACH

- ♦ **TIME INJECTION OF NG TO PREVENT LOSS OF NG DURING SCAVENGING**
- ♦ **LEAN NATURAL GAS FUEL/AIR RATIO TO MINIMIZE NO_x EMISSIONS**
- ♦ **AIRFLOW CONTROL TO MAINTAIN FUEL/AIR RATIO WITHIN AN IGNITABLE RANGE**
- ♦ **USE A CATALYST TO CONTROL HC EMISSIONS**
- ♦ **COMPRESSION RATIO REDUCTION TO ENSURE KNOCK FREE OPERATION**
- ♦ **ELECTRONIC ENGINE CONTROLS TO PROVIDE MAXIMUM FLEXIBILITY AND OPTIMUM CONTROL**
- ♦ **VERY HIGH ENERGY IGNITION SOURCE**

DIESEL PILOT
13 MODE TEST RESULTS

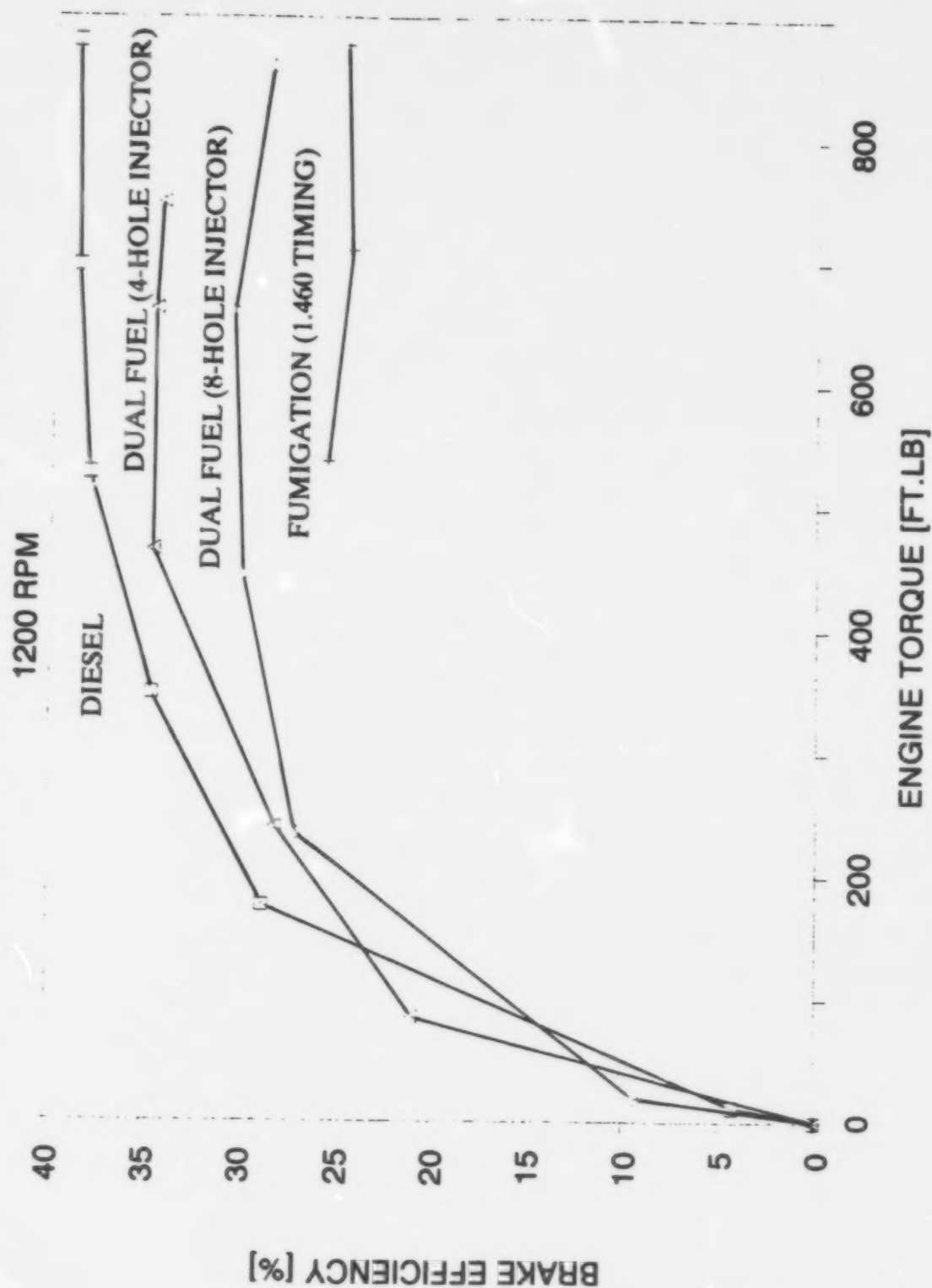
	JANUARY 1990 8-HOLE INJECTOR (12 MG/STROKE)	MAY 1990 4-HOLE INJECTOR (12 MG/STROKE)
THC [G/BHP-HR]	27.0	18.6
CH₄ [G/BHP-HR]	22.9	15.8
CO [G/BHP-HR]	8.31	7.13
NO_x [G/BHP-HR]	6.00	4.24

DIESEL PILOT
EPA TEST CYCLE RESULTS (HOT)
JANUARY, 1990

		BASELINE (NO CATALYST)	PLATINUM CATALYST
THC	[G/BHP-HR]	28.8	24.5
CO	[G/BHP-HR]	8.01	1.33
NO_x	[G/BHP-HR]	5.02	4.59
TOTAL PARTICULATES		0.18	0.05

DIESEL PILOT

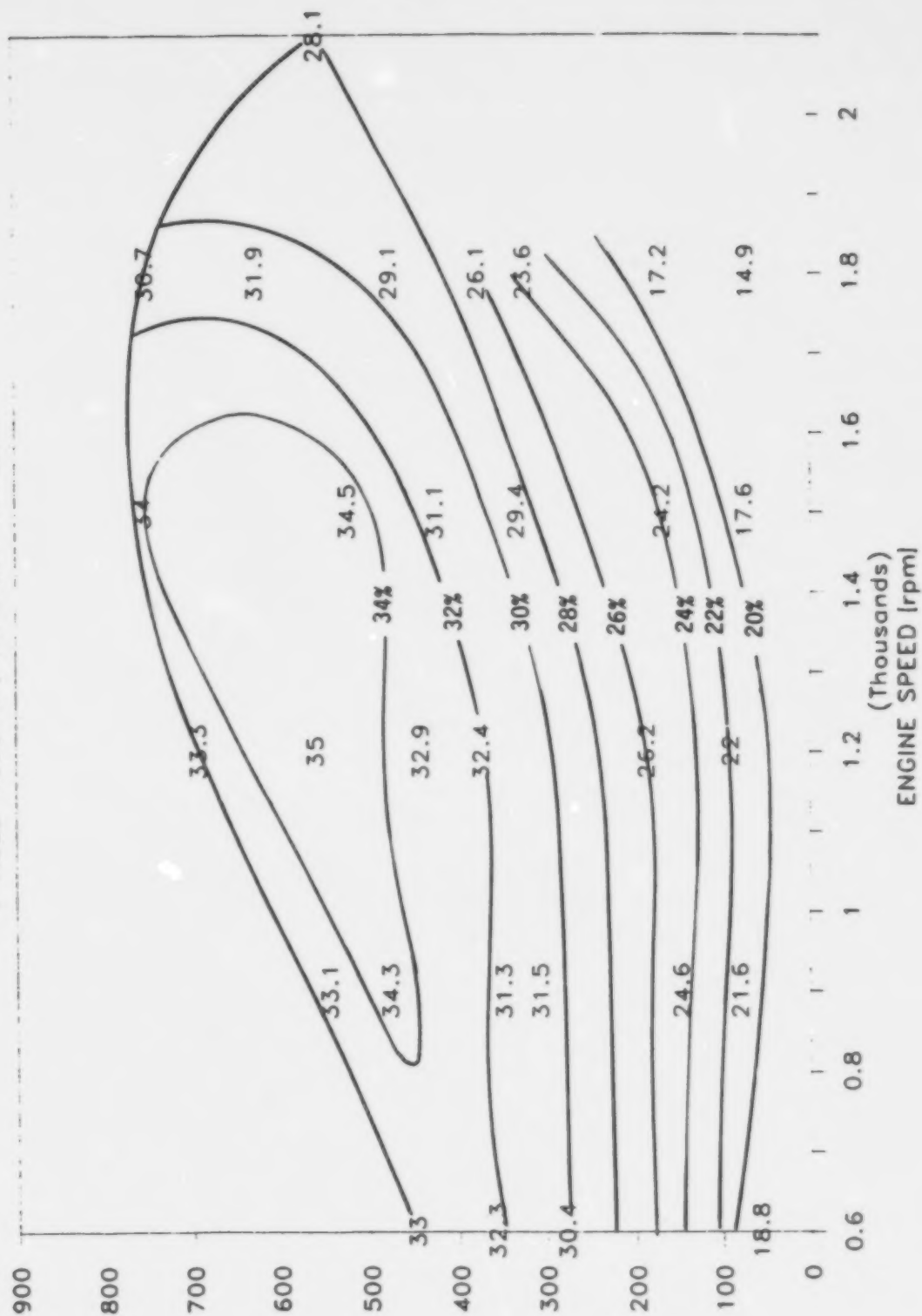
COMPARISON OF BRAKE EFFICIENCY



DIESEL PILOT

EFFICIENCY MAP - DUAL FUEL ENGINE

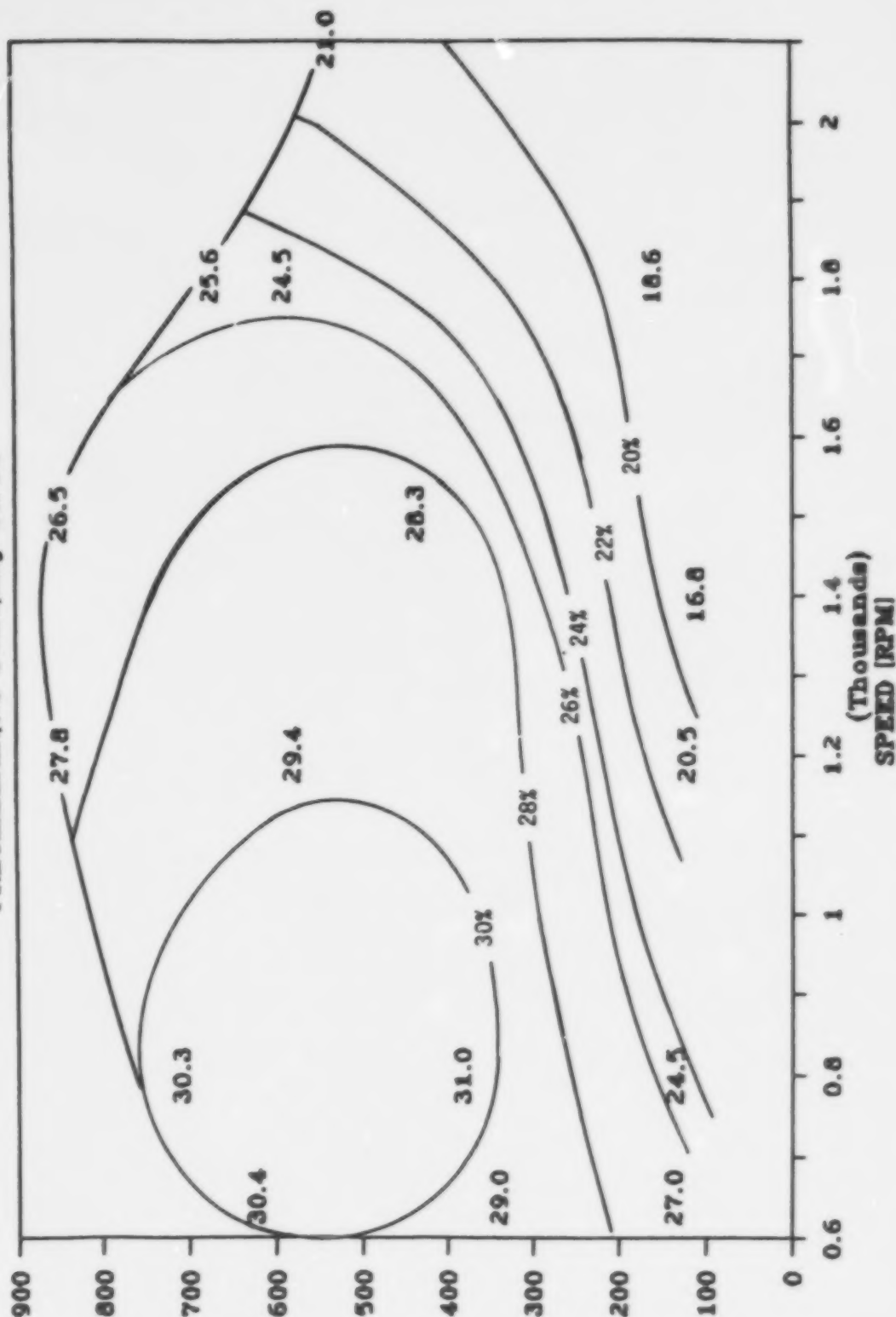
4-HOLE INJECTOR, NO GUIDE VANES



SPARK IGNITION

% EFFICIENCY OVER SPEED/LOAD RANGE

PRECHAMBER, No Swirl, May 24/90



DUAL FUEL WORK IN PROGRESS

- 1. SWIRL VANES FOR IMPROVED HIGH LOAD MIXING**
- 2. FUEL/AIR RATIO STUDIES AT LIGHT LOADS TO
EVALUATE THC REDUCTION POTENTIAL**
- 3. REVISED EXHAUST VALVE TIMING TO MINIMIZE
SHORT CIRCUITING OF NG AT HIGH SPEEDS**
- 4. REVISED DIESEL PILOT SCHEDULE TO FURTHER
REDUCE THC**
- 5. EPA TESTING WITH BEST CONFIGURATION**
- 6. INSTALLATION OF ENGINE IN SECOND
DEMONSTRATION ENGINE (DENVER RTD)**
- 7. DURABILITY WORK**

PRECHAMBER FUTURE WORK

- ♦ **IMPROVED TRAPPING OF NG TO INCREASE EFFICIENCY**
- ♦ **DOCUMENT EMISSIONS**
- ♦ **GENERATE CONTROL MAPS**
- ♦ **IMPLEMENT CONTROL SYSTEM**
- ♦ **DEMONSTRATE ENGINE IN A VEHICLE**

CNG L10 ENGINE FOR TRANSIT BUS

**V. K. Duggal
Cummins Engine Company, Inc.**

**1990 Windsor Workshop on Alternate Fuels
Toronto, June 1990**

OUTLINE

- TECHNICAL RECAP
- PRODUCT DEVELOPMENT
 - GOALS
 - DESIGN CONSIDERATIONS
 - COMPONENT DESIGN & SPEC
 - ENGINE PROFILE
- TECHNICAL STATUS
 - PERFORMANCE
 - MECHANICAL
 - FIELD EXPERIENCE
- SUMMARY
 - WHAT'S NEXT

STATUS SUMMARY (1989 WINDSOR WORKSHOP)

- '1991' BUS PERFORMANCE AND EMISSIONS REQUIREMENTS HAVE BEEN DEMONSTRATED IN LAB.
- ENGINE/COMPONENTS DURABILITY NEEDS YET TO BE PROVEN. DURABILITY TESTS IN LAB ONGOING. ENGINE FIELD EVALUATION JUST STARTED.
- ENGINE/VEHICLE SYSTEM DEVELOPMENT PROGRESSING WITH OEM PARTICIPATION FOR URBAN BUS & SANITATION VEHICLES.
- SIGNIFICANT WORK REMAINS TO BE ACCOMPLISHED FOR COMMERCIAL PRODUCT, INCLUDING EPA CERTIFICATION DURABILITY FOR HD ENGINES.

PRODUCT DESIGN GOALS

- PERFORMANCE
 - 240 HP AT 2100 RPM
 - 750 FT-LBS TORQUE AT OR BELOW 1300 RPM
 - BEST THERMAL EFFICIENCY 37%+
- EMISSIONS (GM/HP-HR)

- NOx	4.5
- PART	.06
- HC	.9 (with oxy catalyst)
- CO	3.0
- MECHANICAL DEVELOPMENT
 - RELIABILITY SIMILAR TO CURRENT DIESEL PRODUCT
 - DURABILITY APPROACHING DIESEL PRODUCT

PRODUCT DESIGN CONSIDERATIONS

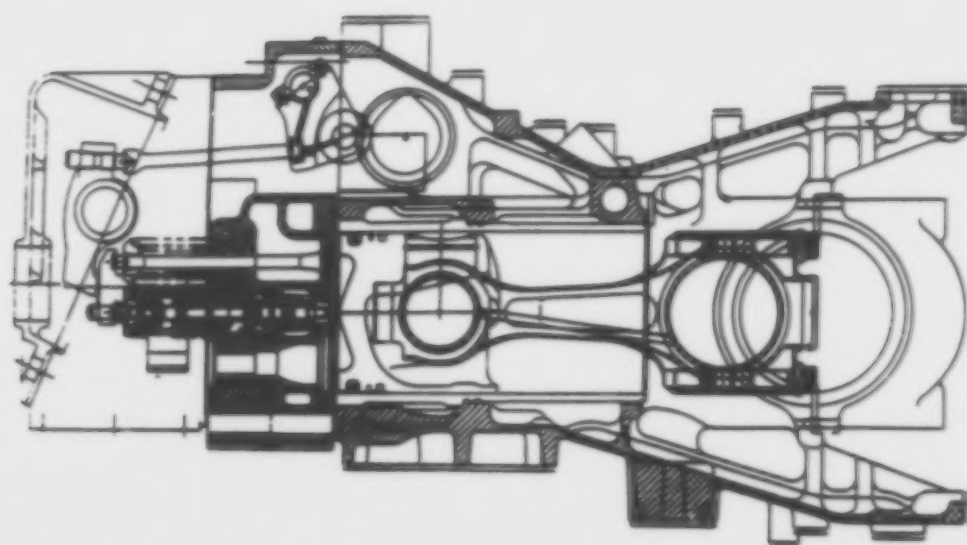
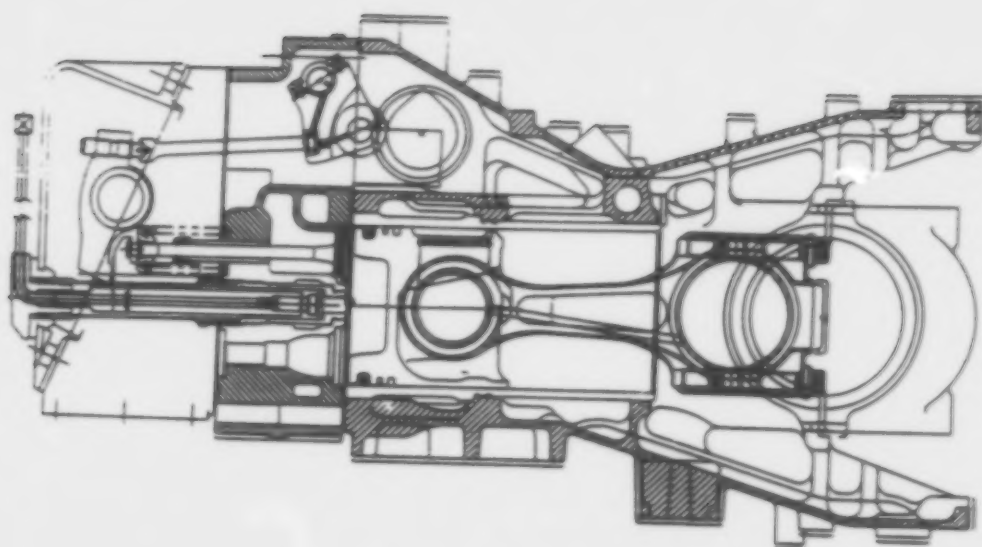
- FUEL/AIR MIXTURE PREPARATION
 - TURBOCHARGER MATCH
 - MIXER CHARACTERISTICS/CONTROL
- COMBUSTION CHARACTERISTICS
 - CR OPTIMIZATION
 - AIR/FUEL REQUIREMENTS
 - COMBUSTION CHAMBER CONFIGURATION
 - SPARK AND FLAME PROPAGATION

PRODUCT DESIGN CONSIDERATIONS (CONT'D)

- MECHANICAL DEVELOPMENT
 - THERMAL LOADING
 - COMPATIBLE MATERIALS
 - IGNITION SYSTEM
 - OIL CONTROL
 - BACKFIRE

PRODUCT DESIGN CONSIDERATIONS (CONT'D)

- SPEED CONTROL
 - HIGH/LOW IDLE
 - TRANSMISSION INTERFACE
 - RF/EM INTERFERENCE
- LUBE OIL
 - ANTI-WEAR
 - LOW ASH
 - CATALYST COMPATIBILITY



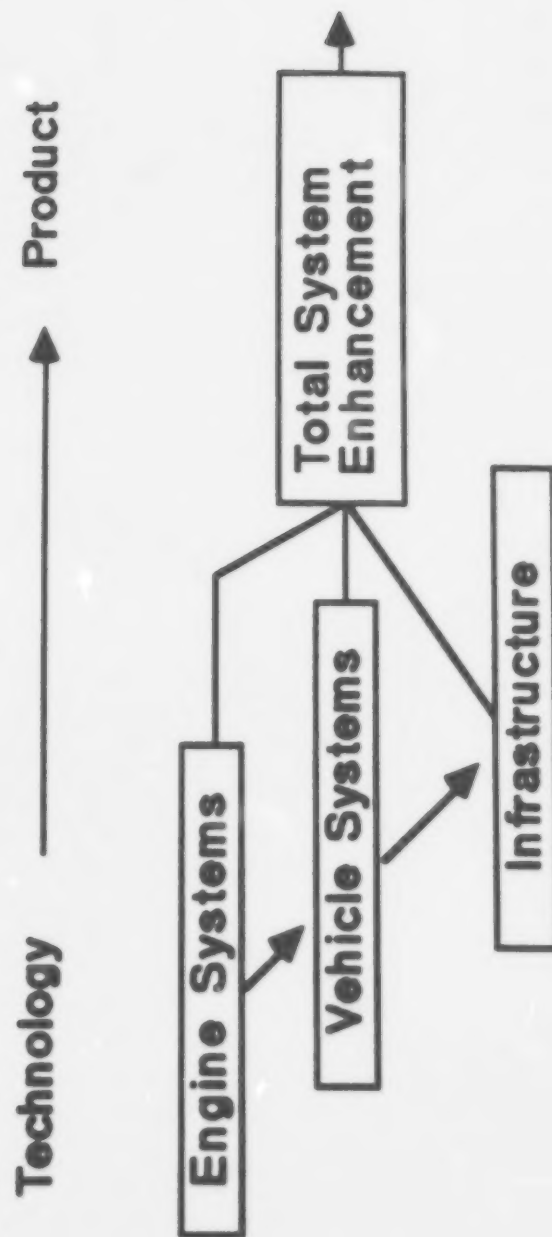
COMPONENT DEVELOPMENT FOR PRODUCT

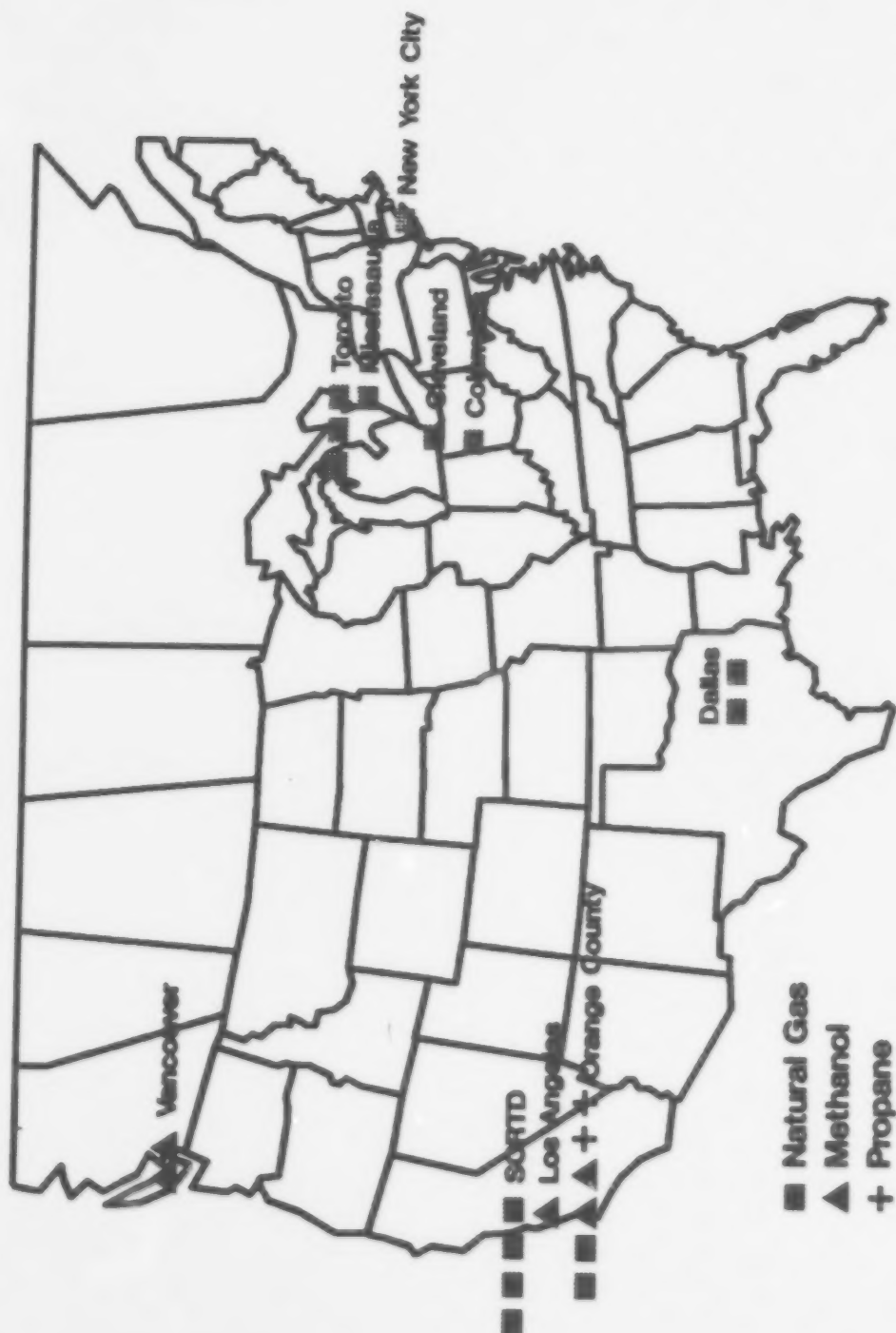
<u>COMPONENT</u>	<u>PROTOTYPE ENGINES</u>	<u>DESIGN VALIDATION</u>
TURBOMACHINERY	H1E ADD-ON WASTEGATE STD. BEARING HSG.	H2D W/INTEGRAL WASTEGATE WATERCOOLED BEARING HSG. OPTIMIZED AIR FLOW
WASTEGATE	DUAL PORT/LINKAGE	SINGLE PORT/LINKAGE
CARBURETOR/ REGULATOR	STD. FOR UPSTREAM OF TURBOCHARGER	MATERIALS COMPATIBLE W/HIGH PRESSURE APPLICATION
IGNITION CONTROL	DISTRIBUTOR LESS IGNITION INPUT SPEED/IMT/IMP NO MANUAL TIMING ADJ.	DISTRIBUTOR LESS IGNITION INPUT SPEED/IMT/IMPT MANUAL/ELEC. TIMING ADJ.
ENGINE TIMING SENSOR	HOUSING W/ANGLE DRIVE WORM GEAR 2:1 SPEED REDUCTION HALL EFFECTS SENSOR	IDENTICAL TO CELECT DIESEL ENGINE POSITION SENSOR READS OFF BACK OF CAM GEAR W/MAGNETIC PICKUP
SPEED CONTROL	STD. WOODWARD	COMPLETE NEW DESIGN MIN/MAX TRANSMISSION INTERFACE DOOR INTERLOCK EMI HARDENED DIAGNOSTICS FOR TROUBLE SHOOTING

CNG L10 ENGINE COMPONENTS

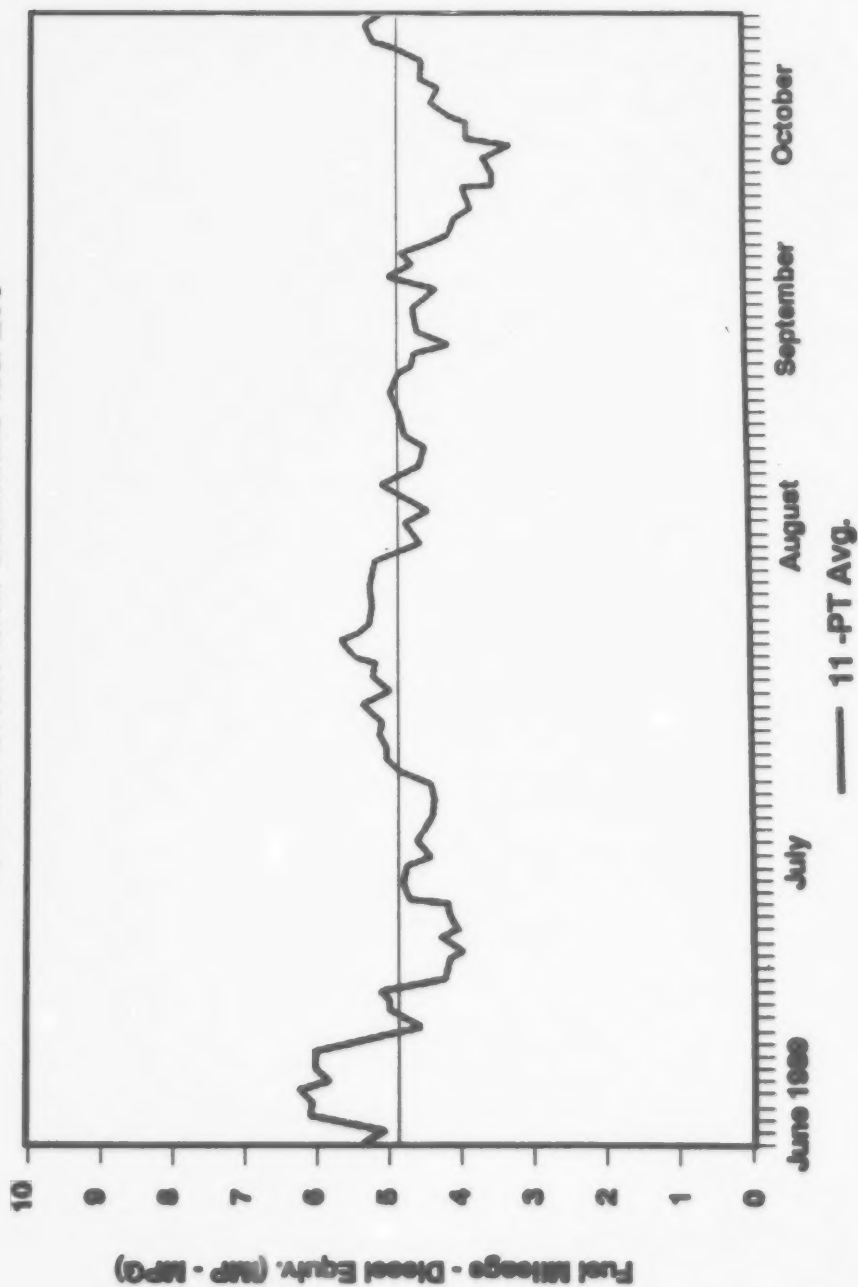
<u>COMPONENT</u>	
PISTON	10.5:1 CR
MIXER	IMPCO 200D
MIXER LOCATION	DOWNSTREAM
REGULATORS	IMPCO MODEL E
IGNITION SYSTEM	ALTRONIC DIS
TURBOCHARGER	HOLSET H2D
RATED BOOST PRESSURE	15 PSI
SPARK PLUGS	CHAMPION PRECIOUS METAL
RATED A/F RATIO	26:1
GOVERNOR	WOODWARD MIN/MAX

Product Development Or Introduction





Mississauga Transit NG Bus #8823
40 Foot Orlon with Cummins NG L10



CUMMINS 1991 URBAN BUS PROTOTYPE NATURAL GAS ENGINE EMISSIONS

- MODIFIED L10
- CATALYTIC CONVERTER
- "LOW BMEP" APPLICATION

COMBUSTION SYSTEM	S.I. LEAN BURN
PARTICULATE, G/BHP-HR	0.06
NOx, G/BHP-HR	4.5
TOTAL HC, G/BHP-HR	0.6
BEST THERMAL EFFICIENCY, %	37

TECHNICAL STATUS

PERFORMANCE DEVELOPMENT

- FOCUS ON LEAN BURN TECHNOLOGY. POTENTIAL TO MEET 1991 BUS EMISSIONS STANDARDS IN LAB SHOWN WITH MECHANICAL AS WELL AS ELECTRONIC A/F CONTROL. OXY CATALYST NEEDED TO MEET HC EMISSIONS.
- 1991 PRODUCT WILL BE BASED ON MECHANICAL FUEL MIXING HARDWARE.
- OXY CATALYST FOR PRE-PRODUCTION ENGINES DEFINED.
- BUS POWER/TORQUE ACHIEVED. BEST THERMAL EFFICIENCY IS 37%.
- HEAT REJECTION SIMILAR TO DIESEL.

TECHNICAL STATUS

MECHANICAL DEVELOPMENT

- FOUR ENGINES COMPLETED 2000 HRS. BUS & THERMAL CYCLE TESTS. SIX DV ENGINES 3000 HRS. DURABILITY TEST PLANNED THIS YEAR. DURABILITY TESTS IN PROGRESS.
- IDENTIFIED TURBOCHARGER BEARING LIFE ISSUE. WATERCOOLED BEARING HOUSING AND INTEGRAL WASTEGATE DESIGN COMPLETE.
- IGNITION SYSTEM FEATURES AND ENGINE TIMING PICKUP SENSOR LOCATION FROZEN.
- NEW ENGINE SPEED AND BUS SAFETY CONTROL GOVERNOR DEVELOPED.
- FUEL MIXER, CATALYST RELIABILITY/DURABILITY NOT PROVEN YET. REDESIGN OF VARIOUS COMPONENTS IN PROGRESS OR FROZEN.

TECHNICAL STATUS

FIELD TEST

- ELEVEN ENGINES IN OEM VEHICLES
 - OBI/FLXIBLE/Crane/GILLIG
- EIGHT UNITS IN SERVICE
 - 53,000 MILES LOGGED (HIGHEST 20,000)
- OFF-THE-SHELF GOVERNOR NOT ADEQUATE FOR SPEED AND BUS SYSTEM CONTROL. NEW GOVERNOR DEVELOPED. EMI/RFI CRITERIA MET IN THESE DESIGNS.
- INTERIOR BUS NOISE LOWER (UP TO 4.5 dBA) THAN DIESEL. EXTERIOR NOISE SIMILAR TO DIESEL. 'LOW NOISE' FRONT ENGINE CONFIGURATION RELEASED.
- FUEL CONSUMPTION ~4 MPG (U.S.) DIESEL EQUIVALENT (MISSISSAUGA).
- OIL CONSUMPTION ~510 MILES/QUART.
- GAS QUALITY AND OIL CONTAMINATION FROM COMPRESSION PROCESS.

ISSUES

- NO EPA EMISSION STANDARDS FOR CNG ENGINES
- DEVELOPMENT OF CERTIFICATION FUEL AND IN-SERVICE COMPLIANCE
- FUEL VARIABILITY FROM REGION TO REGION AND SEASONS
- EMISSIONS DETERIORATION FACTOR NET YET DEVELOPED
- RELIABILITY/DURABILITY FOR NEW TECHNOLOGY
- MAINTENANCE REQUIREMENTS NOT DEVELOPED

SUMMARY

WHAT'S NEXT

- MECHANICAL AND PERFORMANCE DEVELOPMENT ONGOING TO ADDRESS LAB AND FIELD DEVELOPED ISSUES.
- EXPANDED FIELD TEST IN 1990 - UP TO 50 ENGINES.
- PRODUCTION AVAILABILITY IN 1991
- TECHNOLOGY ENHANCEMENT PLANNED.

ACKNOWLEDGMENTS

**WE ACKNOWLEDGE THE FOLLOWING ORGANIZATIONS FOR THEIR
SUPPORT AND FUNDING:**

- **GAS RESEARCH INSTITUTE**
- **CANADIAN GAS ASSOCIATION**
- **ONTARIO MINISTRY OF TRANSPORTATION**
- **ONTARIO MINISTRY OF ENERGY**



HEAVY-DUTY ALTERNATIVE-FUELED ENGINE DEVELOPMENT

Steven R. King
Engine and Vehicle Research Division

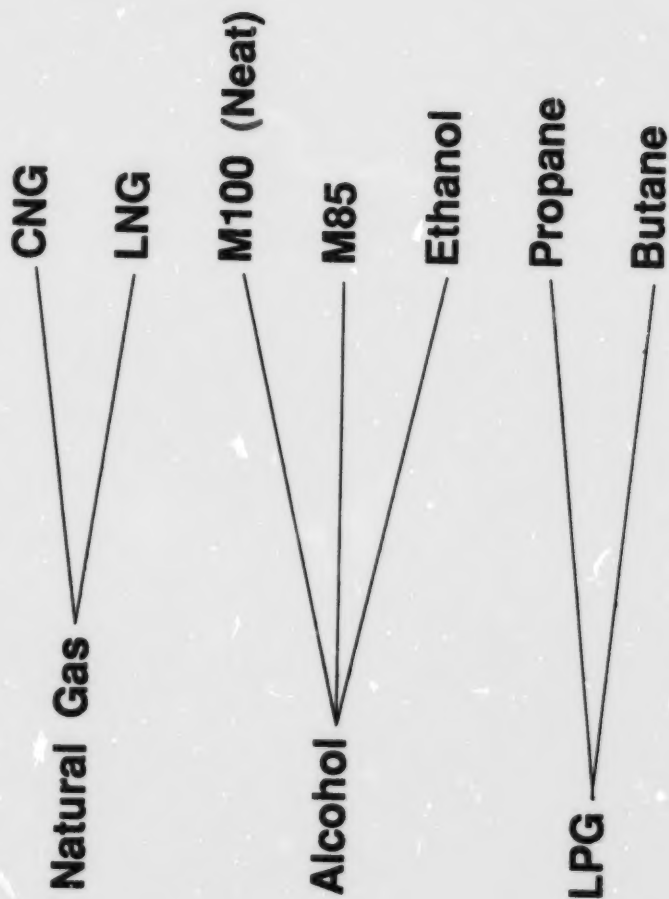
OVERVIEW

- **Why the push for alternative fuels?**
- **What are alternative fuels?**
- **Engine technology for R&D**
- **SwRI projects/results**

IMPETUS FOR USING ALTERNATIVE FUELS

- Environmental
 - air quality (CO, NO_x, Ozone)
 - global warming
- Energy security
- Economic
- Vehicle performance
- Regulations

CURRENT CLEAN ALTERNATIVE FUELS

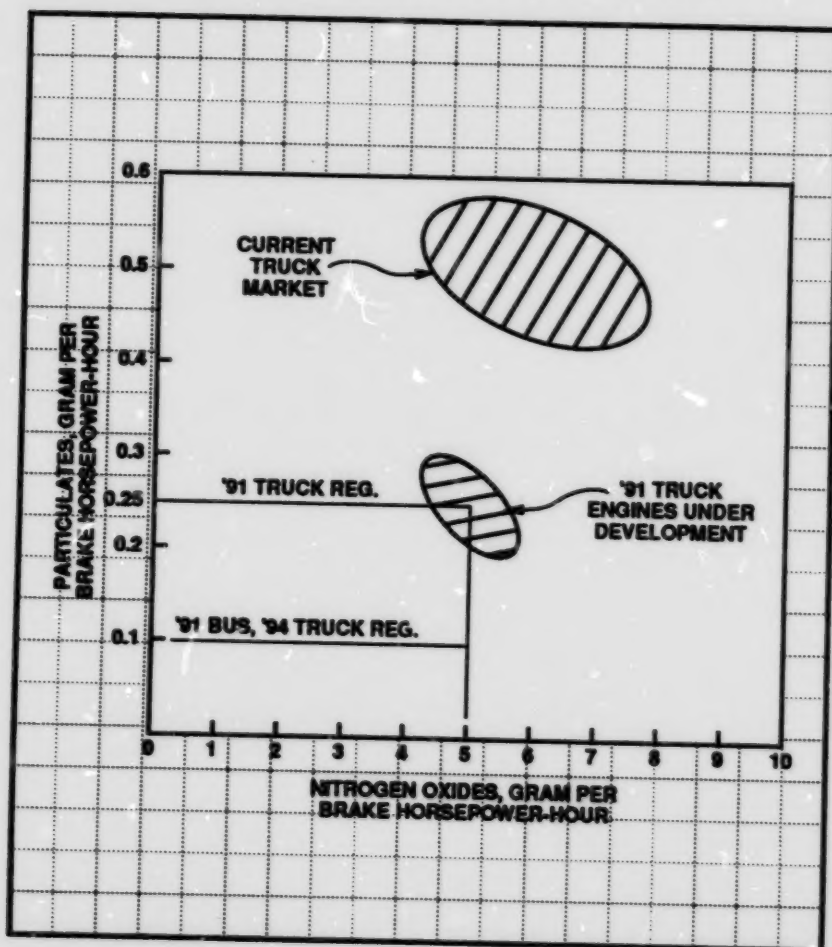


OTHER "ALTERNATIVE" FUELS

- **Reformulated Gasoline**
- **Oxygenated Gasoline**
- **Low Sulphur Diesel**
- **Hydrogen**
- **Electricity**



HEAVY-DUTY DIESEL EMISSIONS

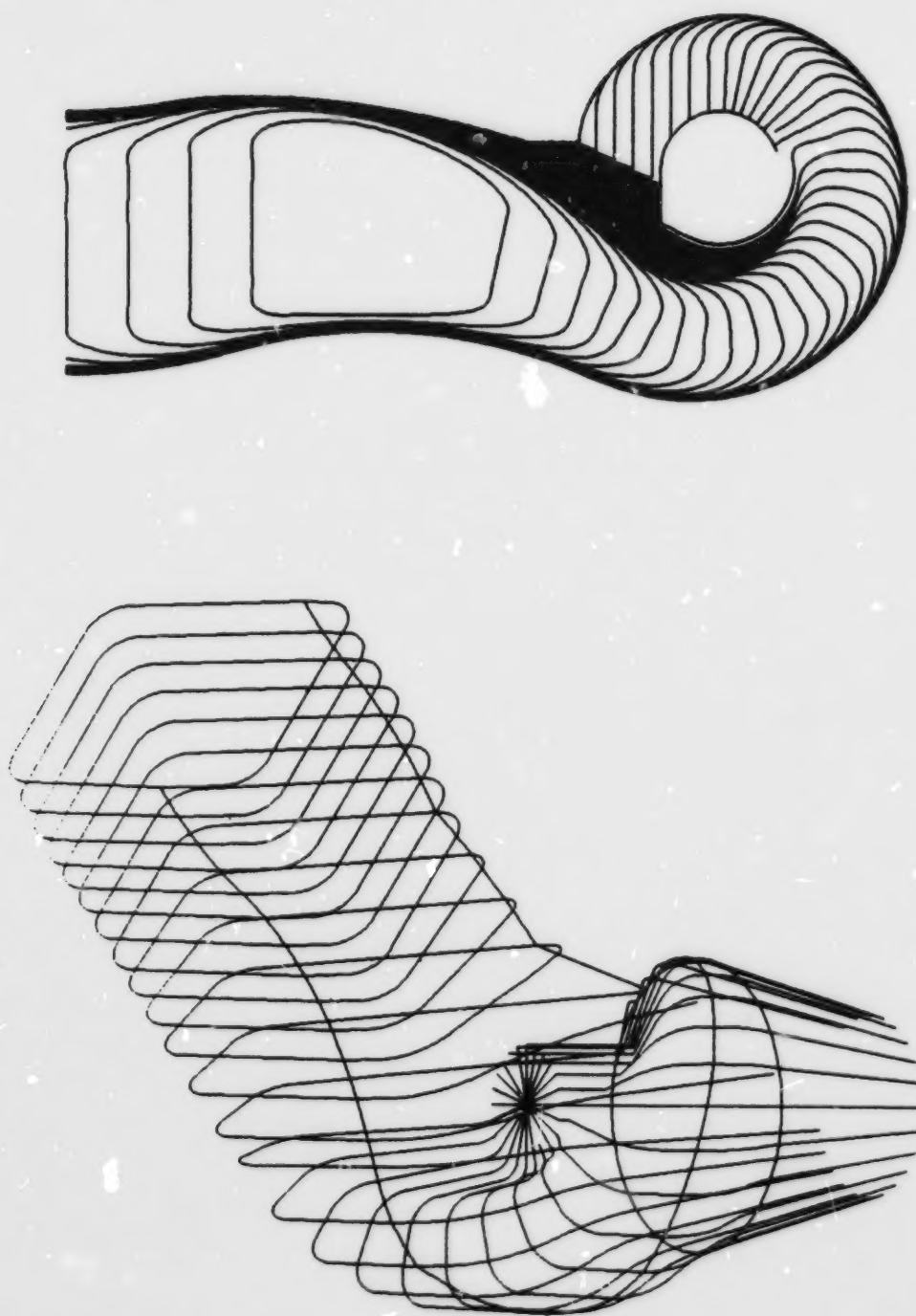


HEAVY-DUTY ENGINE R&D

- "Clean" diesels
- Gaseous-fueled engines (CNG, LNG, LPG)
 - combustion systems
 - durability

1994 CLEAN DIESEL DEVELOPMENT

- Air-fuel ratio > 30:1
 - cylinder pressure > 2300 psi (high output)
- Optimized combustion chamber (mixing)
 - nozzle configuration
 - chamber design (preserve swirl)
 - minimize dead volume
- Provide optimum swirl level and quality (mixing)
 - intake port design
- Improved injection characteristics
 - high pressure (unit or advanced in-line)
 - rising rate
 - well-defined end of injection



Design of Intake Port by 3-D CAD.

SwRI Flow Bench. The effect on swirl of rotating cylinder

Non-Dimensional Swirl (Nr)

0.8

0.6

0.4

0.2

0

Δ 10 mm lift

○ 7 mm lift

Directed Components

Helical Components.

Normal position of valve
relative to the cylinder.

Cylinder Rotation from Datum (degrees)

360

320

280

240

200

160

120

80

40

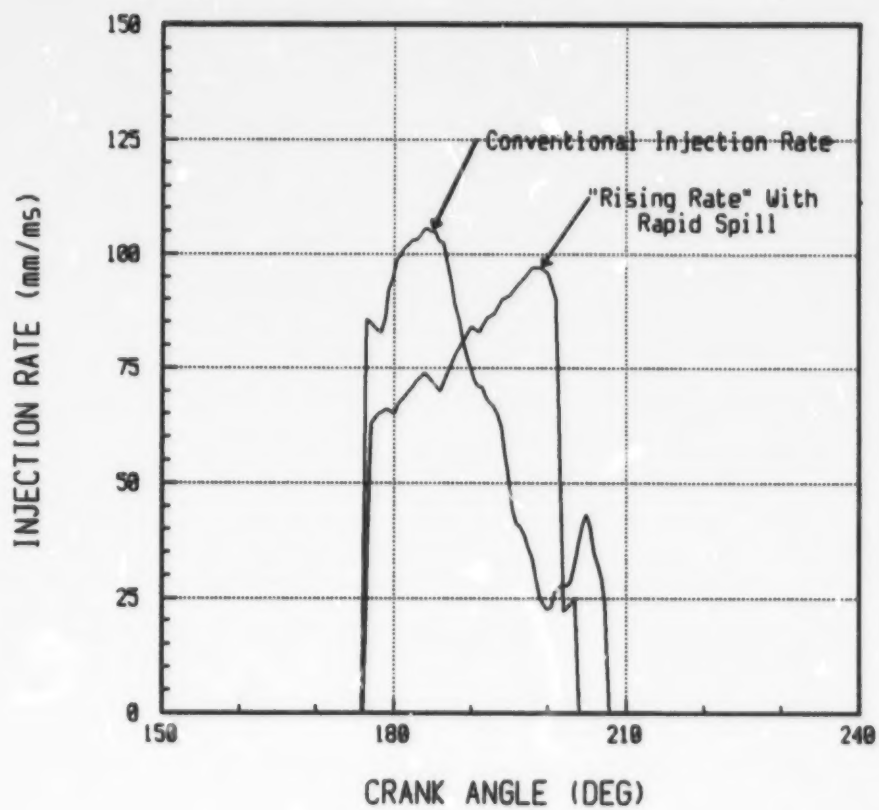
0

Rotation of cylinder
about valve
from datum.

Datum.
(crankshaft axis)

Components of Swirl.

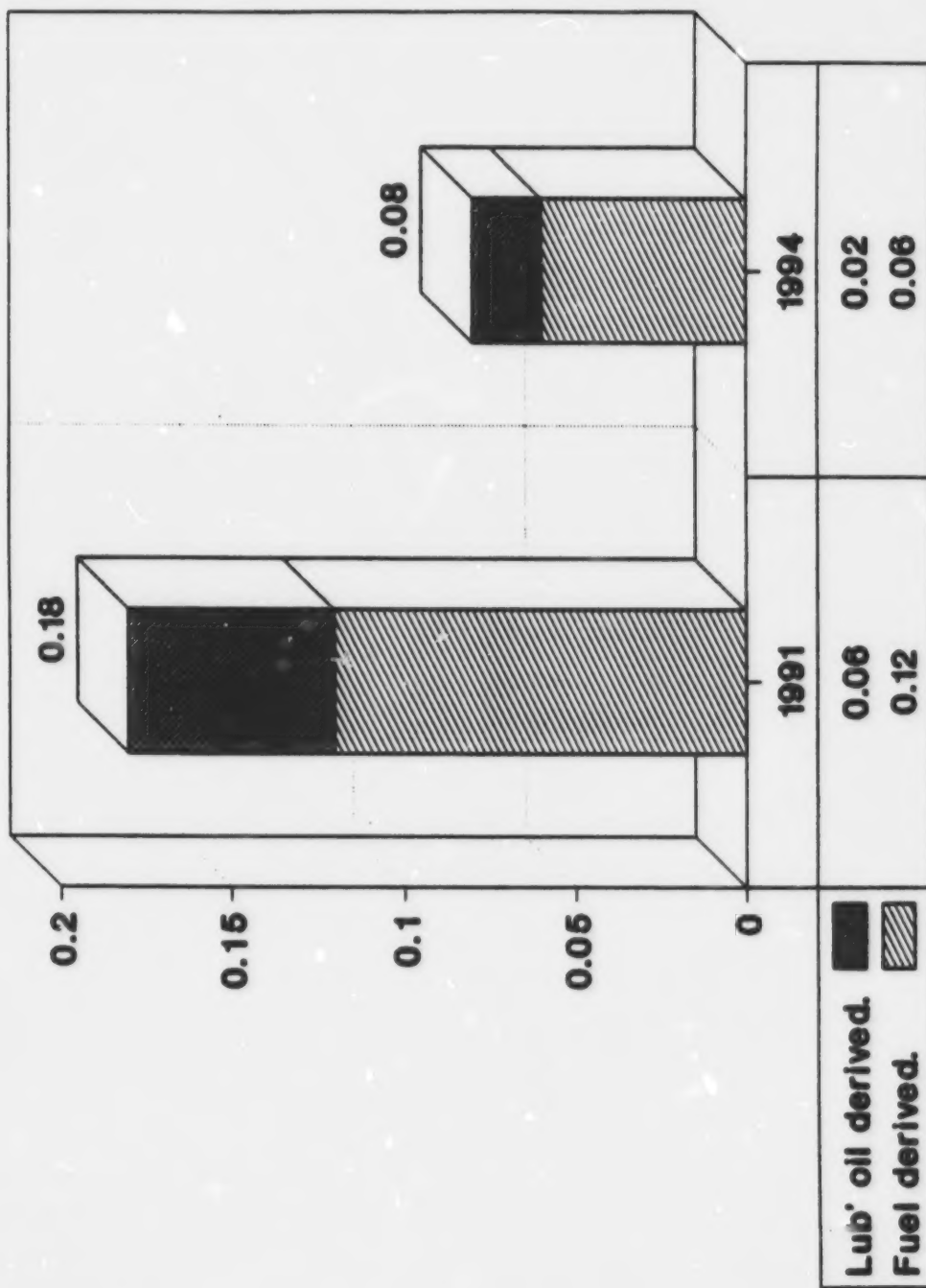
port23



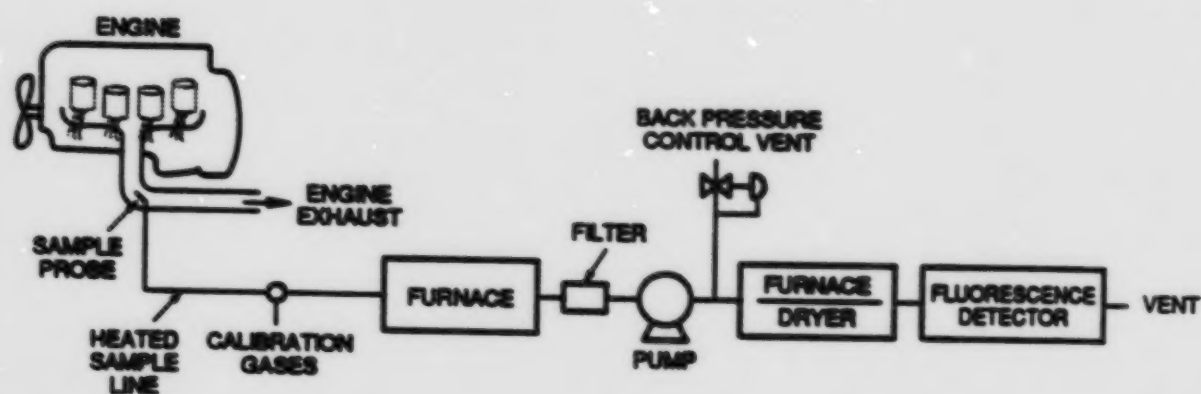
**DIFFERENCES IN INSTANTANEOUS
RATES OF INJECTION**

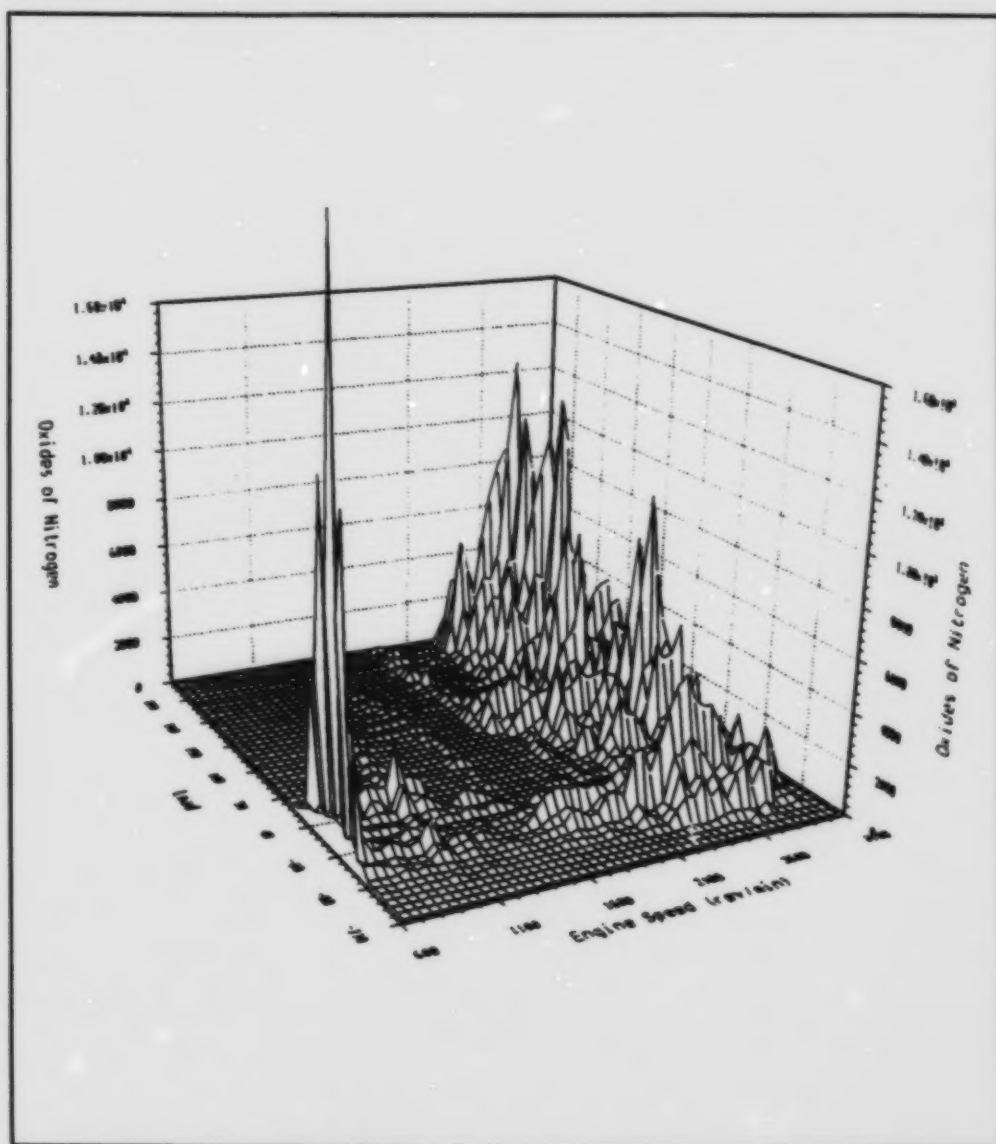
1994 CLEAN DIESEL DEVELOPMENT (Cont'd)

- Low-sulfur diesel (<0.05%)
- Reduced oil consumption
 - ring motion control
- Advanced turbomachinery (VNT, VVT)
- Low temperature aftercooling
- Transient testing trade-offs
 - NO_x and particulates through electronic control of timing and prelift
- Catalysts/Particulate traps



REAL-TIME OIL CONSUMPTION MEASUREMENT SYSTEM

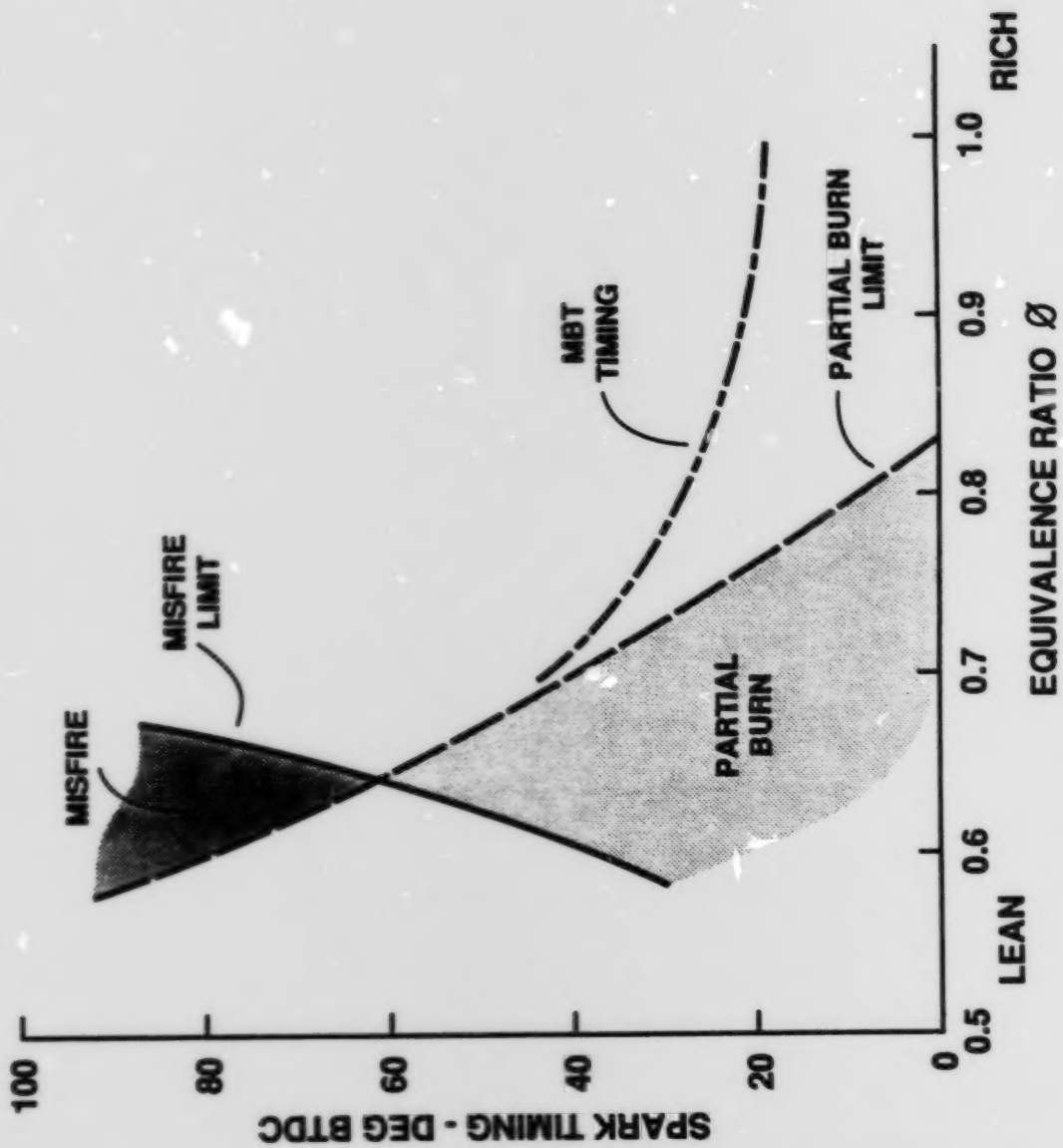




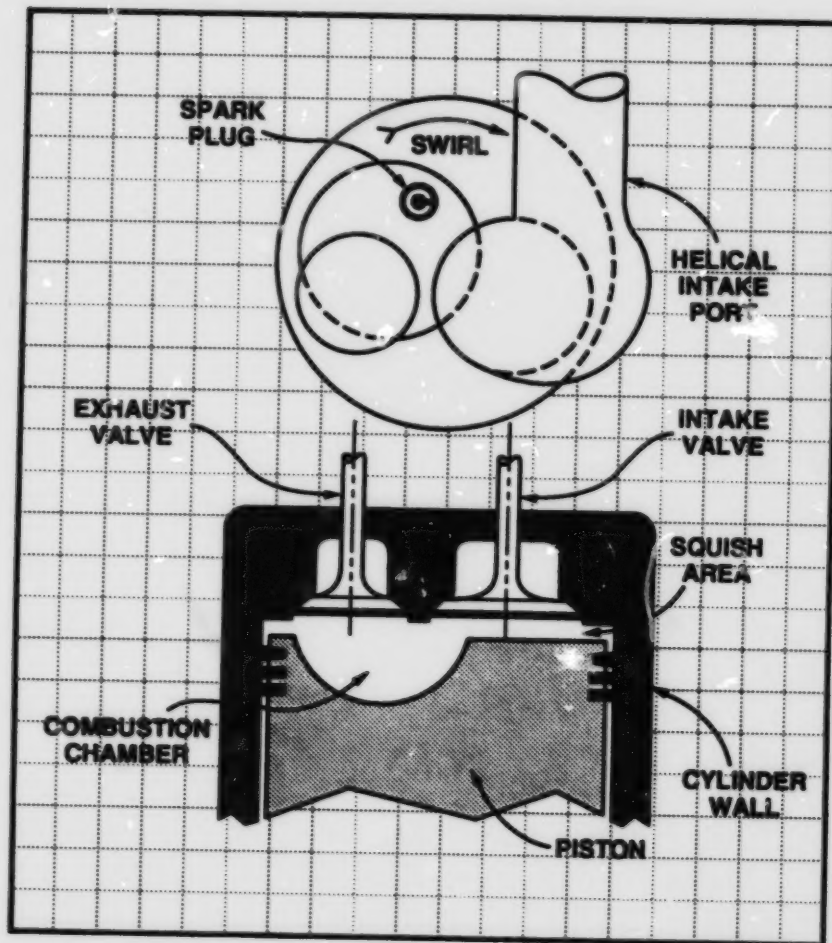
GASEOUS FUEL COMBUSTION SYSTEMS FOR VEHICLES

- Rich-burn
- Stoichiometric
- Lean-burn open chamber
- Lean-burn stratified charge
 - precombustion chamber
 - dual fuel

LEAN MISFIRE



OPEN CHAMBER



GAS OPEN CHAMBER COMBUSTION SYSTEM

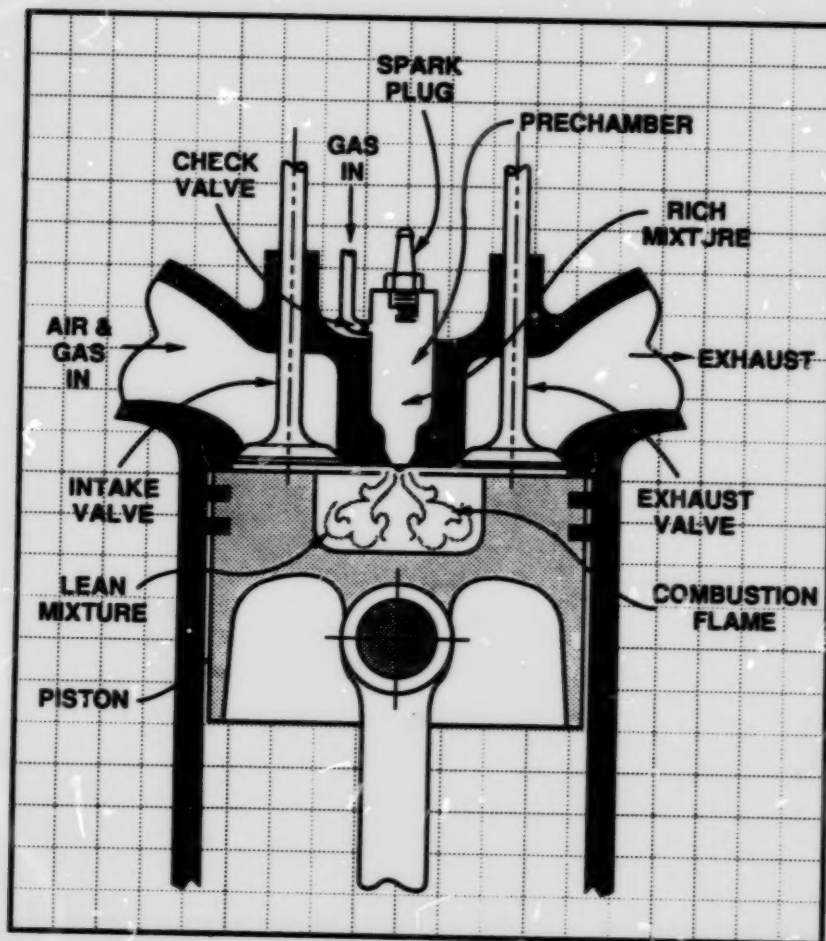
Characteristics

- Low NO_x emissions potential
- High efficiency potential
- Turbocharging and aftercooling required
- Simple mechanical fuel control possible
(homogeneous premix preferred)

Technical Barriers

- High HC emissions (oxidizing catalyst)
- Electronic control system beneficial

PRECOMBUSTION CHAMBER



GAS PRECHAMBER COMBUSTION SYSTEM

Characteristics

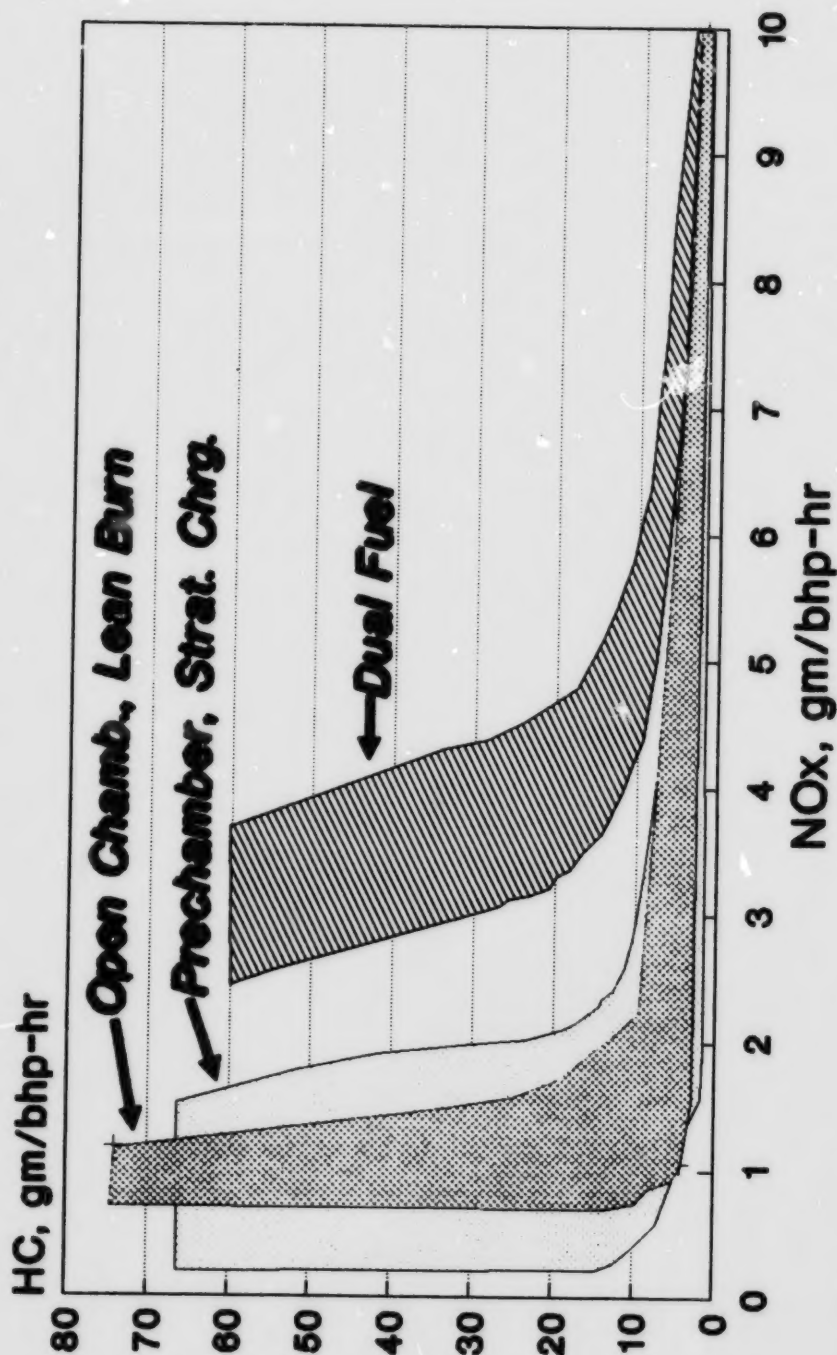
- Very low NO_x emissions potential
- Highest efficiency potential
- Turbocharging and aftercooling required
- Unthrottled operation possible

Technical Barriers

- High HC emissions (oxidizing catalyst)
- Complicated fuel control strategy
(electronic control mandatory)

HC vs NOx TRADE-OFF

Gas Engine Combustion Systems

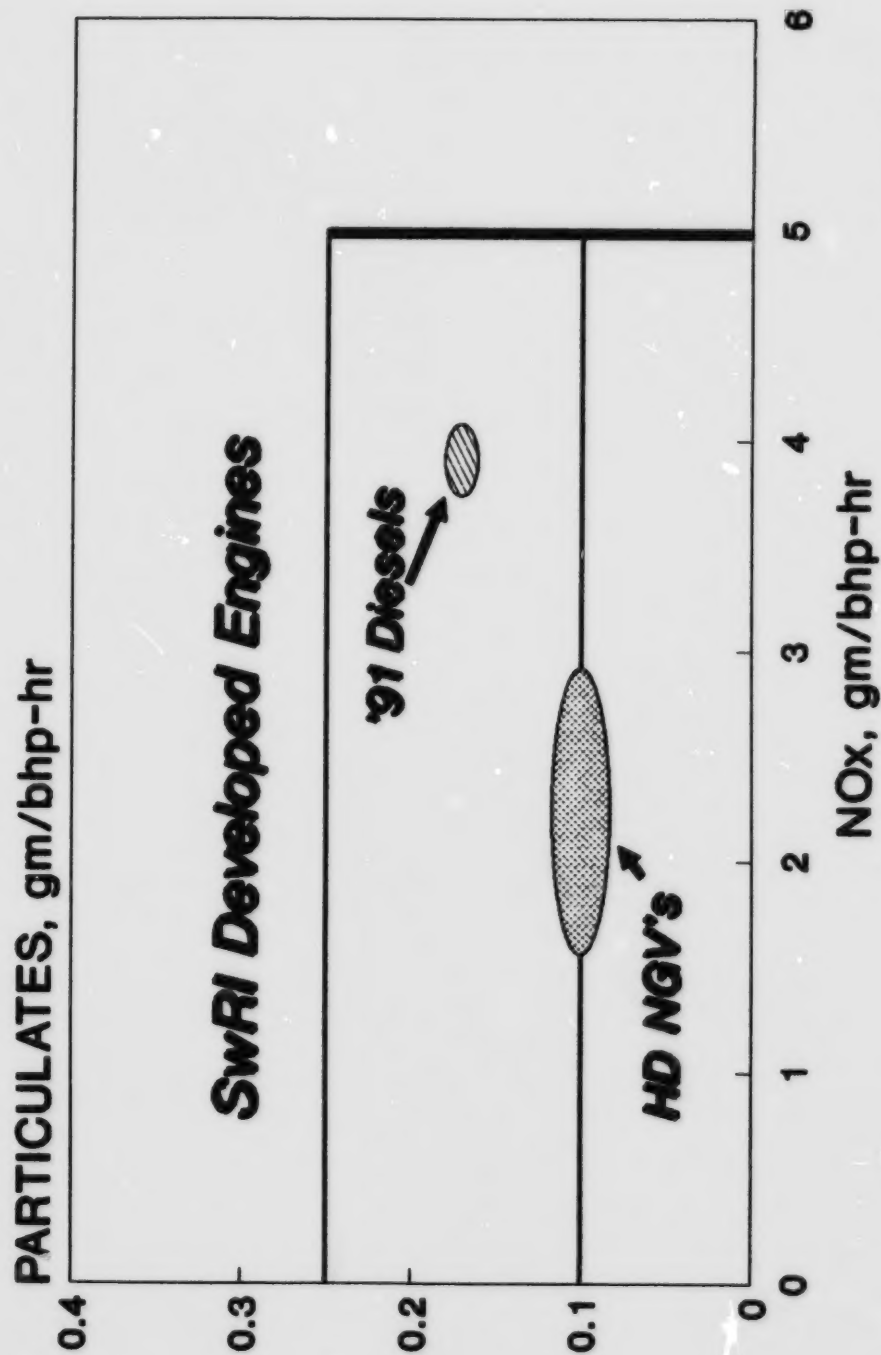


SwRI Test Data

SV/0406/HCNOX/600608

HD ENGINE EMISSIONS

US Standards, Transient Cycle



SV/HDENG/STRDS/800811

SwRI GAS ENGINES PROJECT REVIEW

- 3.7L CNG transient results
- Gaseous emissions reduction technology

CONVERSION OF A 3.7L DIESEL ENGINE TO DEDICATED CNG

Application

- Medium-duty delivery van

Objective

- 100 percent CNG conversion
- 1994 heavy-duty diesel transient emissions
- High efficiency

ENGINE CONFIGURATION

- 4-cylinder (diesel derivative)
- 3.7 liter (4" bore x 4.5" stroke)
- Lean-burn open chamber combustion system
- 10:1 compression ratio, dished bowl
- Turbocharged (no wastegate)
- Aftercooled (120°F maximum)
- Gas carburetor
- Throttled
- Direct-fire ignition

3.7L HD TRANSIENT RESULTS

	Actual	Standard
THC/NMHC	13.7/1.3*	1.3
CO	3.55	15.5
NO _x	1.68	5.0
Particulates	0.10	0.10
*Numbers are in g/bhp-hr.		



TECHNOLOGY BASED RESEARCH GASEOUS EMISSIONS REDUCTION TECHNOLOGY

Low Emissions Catalyst For Natural Gas

- HC oxidation
- NO_x reduction

Gas Composition Effects on Performance and Emissions

- Single-cylinder research engine
 - bowl in piston
 - wedge
- Multi-cylinder engines
 - lean-burn
 - stoichiometric

LOW EMISSIONS CATALYST FOR NATURAL GAS

Background

- Gas engines will require catalysts to reduce HC emissions to meet standards
- Gas engine HC composition is primarily methane
- Conventional catalysts have poor methane conversion activity
- NO_x conversion efficiency uncertain

Objectives

- Determine status of methane catalyst control programs and technology
- Characterize the effect of varying fuel-air ratios on NO_x conversion efficiency
- Characterize the effect of varying fuel-air ratios and exhaust temperatures on hydrocarbon (methane, etc.) oxidation efficiency

LOW EMISSIONS CATALYST SCREENING PROGRAM RESULTS/TECHNOLOGY TRANSFER

- Analysis of SOA for gas engine catalyst effectiveness
 - lean-burn
 - stoichiometric
- Proper A/F ratio for best NO_x reduction on stoichiometric engines (i.e., operational window)
- Influence of exhaust catalyst temperature on hydrocarbon oxidation efficiency
- Exhaust product speciation (i.e., for hydrocarbons)
- Identification of gas engine catalyst technology needs
- Feedback to catalyst manufacturers on catalyst performance

VARIABLE GAS COMPOSITION EXPERIMENTS

Objective:

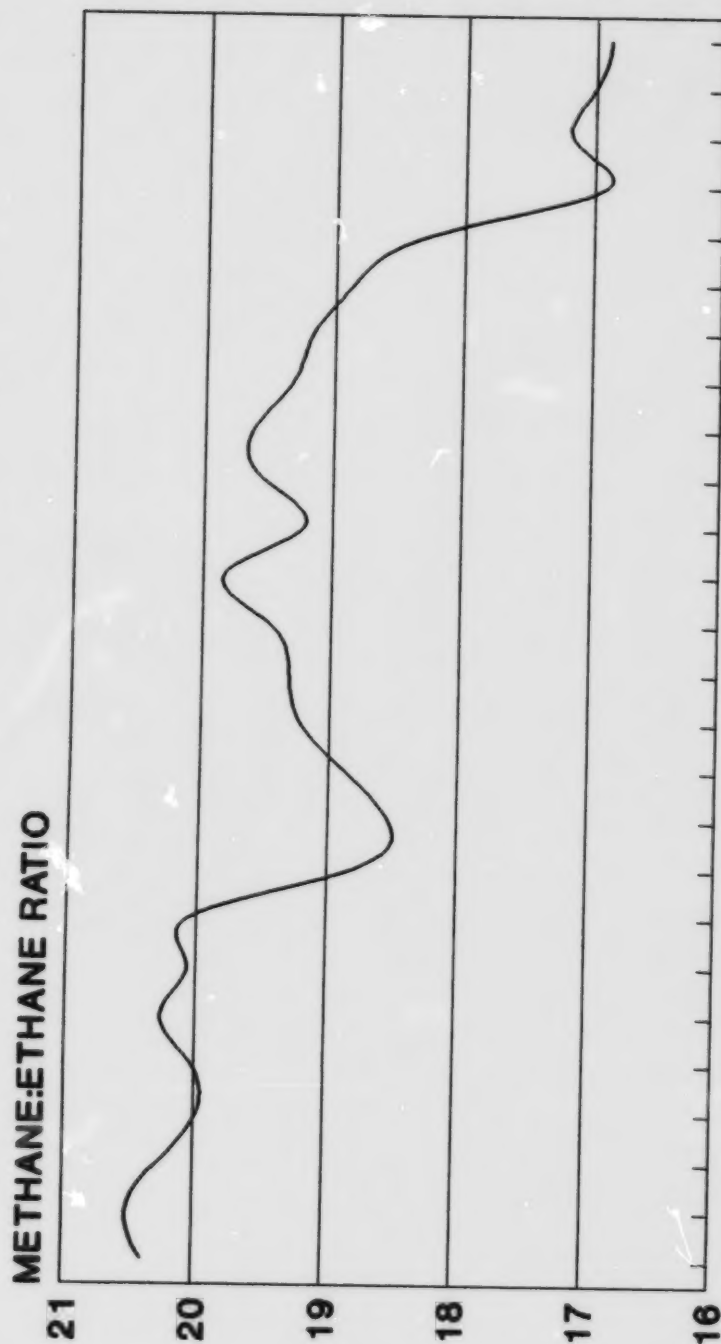
- 1) Determine the effects of gas composition on performance and emissions
- 2) Develop relationships between performance, emissions and gas composition
- 3) Support NGV industry efforts
- 4) Transfer information to manufacturers, regulators, etc.

Approach:

- Single-cylinder experiments
- Multi-cylinder tests

METHANE/ETHANE RATIO

SwRI Gas Supply, 4 Day Period



Hourly Samples, 8am - 5pm (Approx.)

Sampled JUN 4-7, 1990

SV/OAFC/ME/900611

RESEARCH ENGINE EXPERIMENTS

- Independent variables
 - gas composition (C_1 - C_8 , CO_2)
 - compression ratio, 8-16
 - equivalence ratio, 0.7-1.3
 - speed
 - BMEP
- Dependent variables
 - power
 - efficiency
 - gaseous emissions
 - other

SINGLE-CYLINDER ENGINE EXPERIMENTS GAS COMPOSITION RANGES

	CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂	C ₆ H ₁₄	N ₂	CO ₂
Mean	93	3	1	0.5	0.1	0.5	1.5	0.5
Standard Dev.	5.5	2.6	1.4	1.0	0.3	0.1	2.9	0.5
Min.	73	0	0	0	0	0	0	0
Max.	99	13	8	7	3	1	17	2
RANGES FOR TEST MATRIX DESIGN								
Min	85	0	0	0	0	--	--	0
Max.	100	10	4	3	2	--	--	3
Summary data for natural gas composition based on Griffiths et. al. tabulation in mole %.								

GAS COMPOSITION PROGRAM MULTI-CYLINDER TEST

- Use of commercial multi-cylinder engines
 - Cummins lean-burn L10
 - GM 7.4L stoichiometric
- Operate on Federal Transient Cycle with and without exhaust catalysts
- Exhaust product speciation
 - NO_x
 - CO
 - hydrocarbons
 - particulates
 - soluble organics
- Four characteristic gas compositions

GAS COMPOSITION PROGRAM MULTI-CYLINDER TEST

- Four gas compositions tested on each engine
 - with catalyst
 - without catalyst
- Four gas compositions tested on single-cylinder research engine
 - correlation of "ideal" with actual
- Test results transferred to engine manufacturers, regulators (EPA, CARB), and other interested parties

METHANOL FUEL ADDITIVE DEMONSTRATION

**John A. Russell
E. Robert Fanick
William E. Likos
Lawrence R. Smith
Southwest Research Institute**



**and
Manjit Ahuja
California Air Resources Board**

METHANOL FUEL ADDITIVE DEMONSTRATION

John A. Russell
E. Robert Fanick
Lawrence R. Smith
Southwest Research Institute

Manjit Ahuja
California Air Resources Board

The California Air Resources Board (CARB) is considering the replacement of conventional fuels with methanol as one potential strategy for achieving significant reductions in motor vehicle emissions. However, safety and technical problems associated with neat methanol fuel (M100) have prevented its widespread acceptance and use. In 1989, CARB contracted with the Institute to identify, evaluate, and demonstrate additive package constituents to enhance certain key properties:

- o Lubricity
- o Luminosity
- o Low temperature flammability
- o Taste, odor, and color

An extensive literature search and contacts with key members of the fuels and additives technical community identified a considerable number of candidate compounds and proprietary formulations. A laboratory bench test screening program then emphasized lubricity, luminosity, and flammability, since taste, odor, and color can easily be accommodated at additive concentrations in the ppm range. The prescribed maximum total additive package concentration was 5vol% (M95). Additives were first screened individually on separate apparatus for either lubricity, luminosity, or flammability, and then tested in combination to ensure compatibility. Lubricity targets were easily attained at concentrations of 0.12wt% using corrosion inhibitor-type additives. Similarly, low temperature flammability criteria were met using 2.5vol% of butane or butene. Significant luminosity increase above neat methanol (M100) was attained within the constraint of the remaining 2.5vol%; the flame visibility was deemed to be acceptable under twilight-to-dark conditions. Considerable further luminosity improvement was achieved by extending the total additive package constraint to 6 or 7vol%.

Additive package nominees are identified (together with suggested relative proportions for use in full-scale vehicle evaluations) in a final technical report on this study which is currently under review by CARB technical staff.

METHANOL FUEL ADDITIVE DEMONSTRATION

***Task 1: Literature Search & Additive
Evaluation***

Task 2: Short-Term Vehicle Demo

Task 3: Long-Term Vehicle Demo

1989-1991



KEY MeOH PROPERTIES

- **Lubricity**
- **Luminosity**
- **Low-Temp Flammability**
- **Taste – Color – Odor**

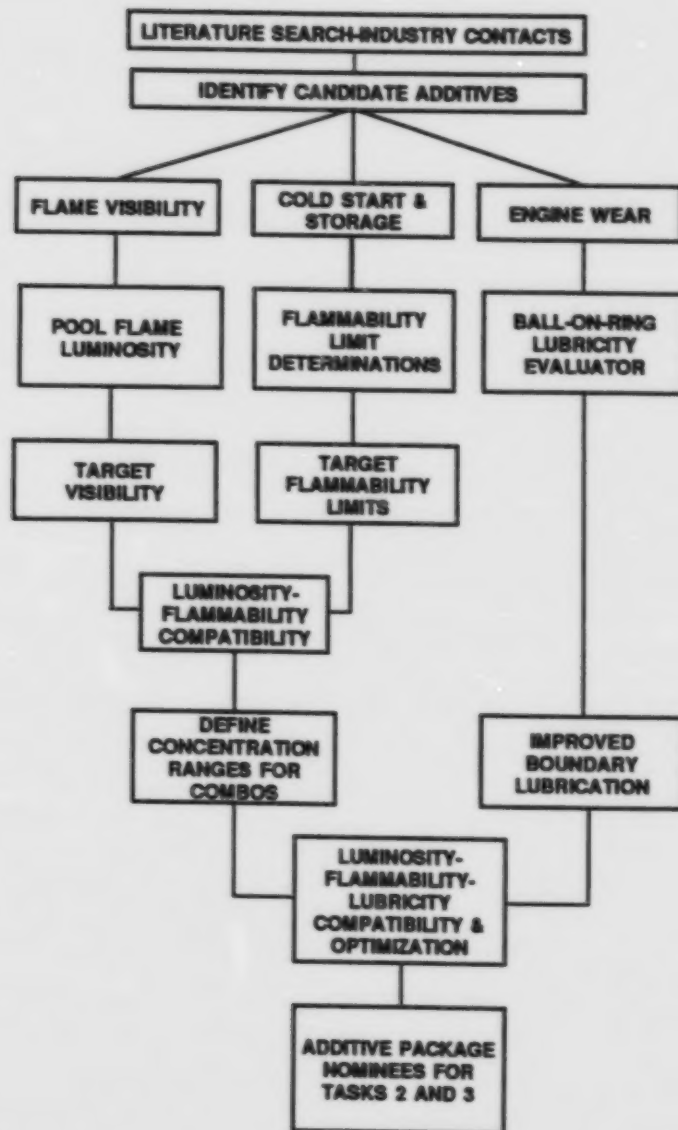


CONSTRAINTS & CRITERIA

- Flam < Ambient
- Start/Warmup 0° F
- Define Min Luminosity
- Identify & Detect
- U.C. Lubricity
- Emissions 50% M85
- Mats Compatibility
- Cheap – Available
- LD & HD MeOH Systems

5 Vol% Additives Package





LUBRICITY

Ball-On-Cylinder-Lubricity Evaluator

1000 gms

240 rpm

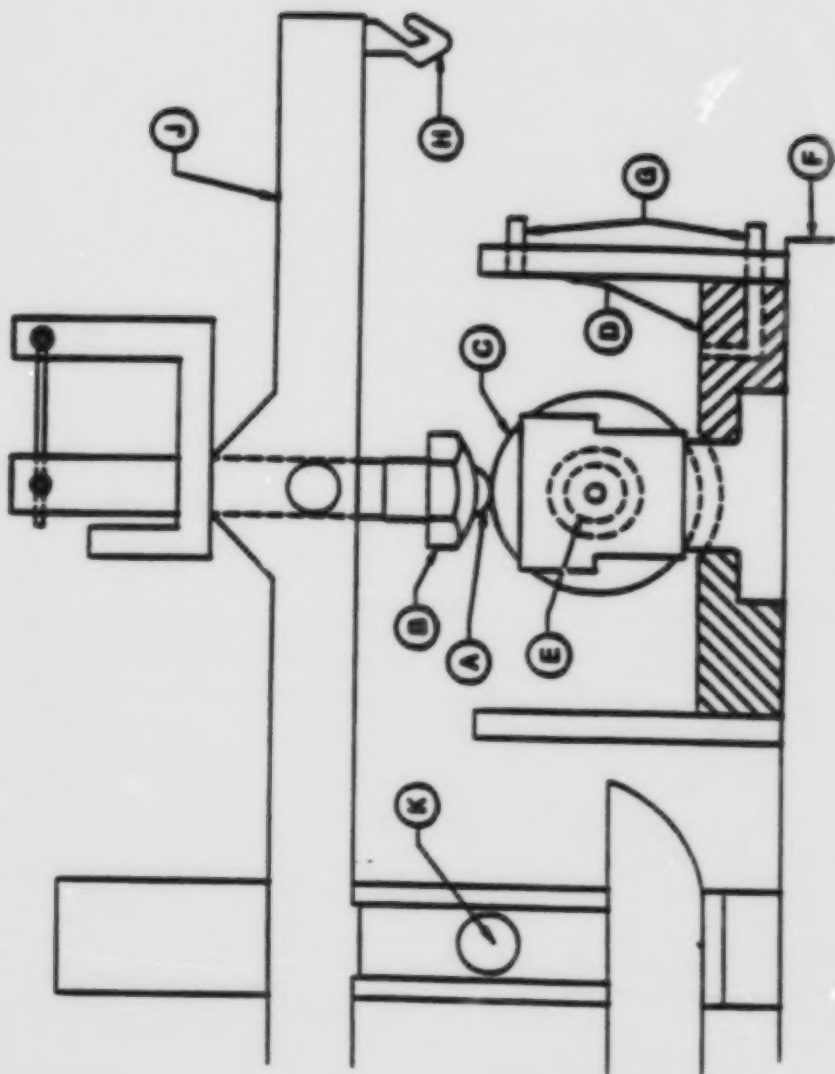
30 minutes

50 mL MeOH

75° F

0.03 - 0.6 Wt% Additive





$$\% \text{Change} = \left[\frac{\text{WSD}_i - \text{WSD}_{\text{MeOH}}}{\text{WSD}_{\text{MeOH}}} \right] \times 100 \leq 15\%$$

$$\text{WSD}_{\text{MeOH}} = 0.55 \text{ mm}$$

$$\text{WSD} \leq 0.47 \text{ mm}$$



LUBRICITY ADDITIVES

<u>UOP</u>	<u>DuPont</u>	<u>Cortec</u>	<u>Lubrizol</u>	<u>Nalco</u>	<u>ChemLink</u>
Unicor J	DCI-4A	Metacor 704	OS86454	VX3181	IPC4410
			OS86455	VX3182	
			OS86458		
			OS86460		

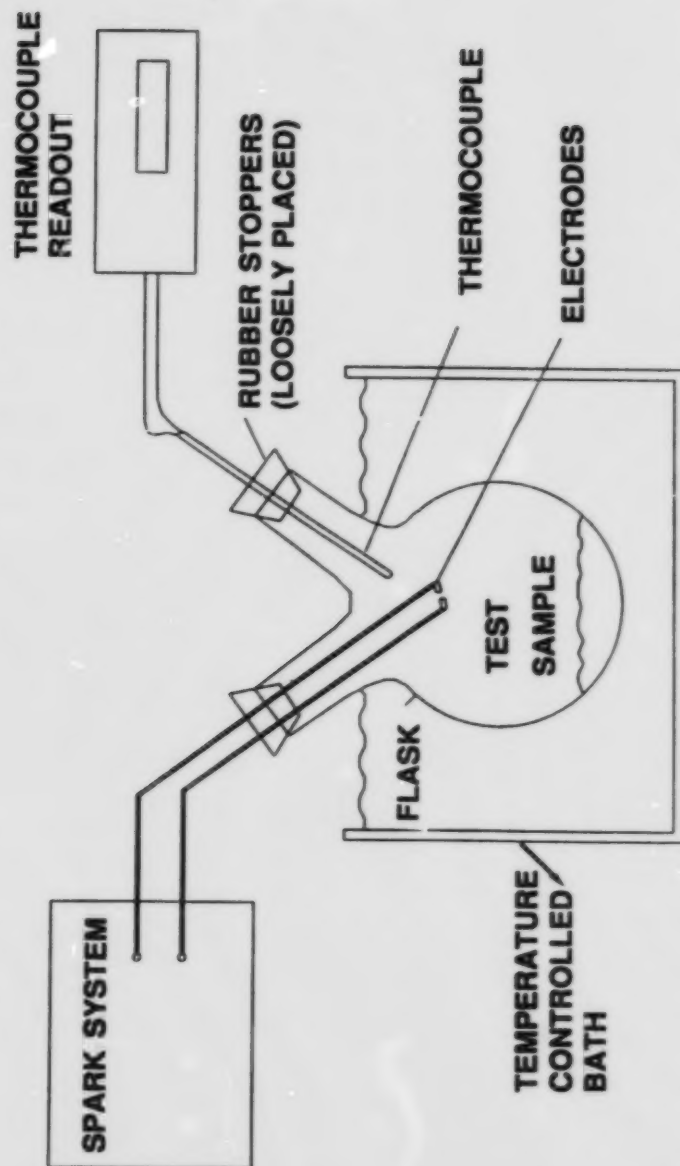
0.12 Wt%
-16 to -27% ΔWSD



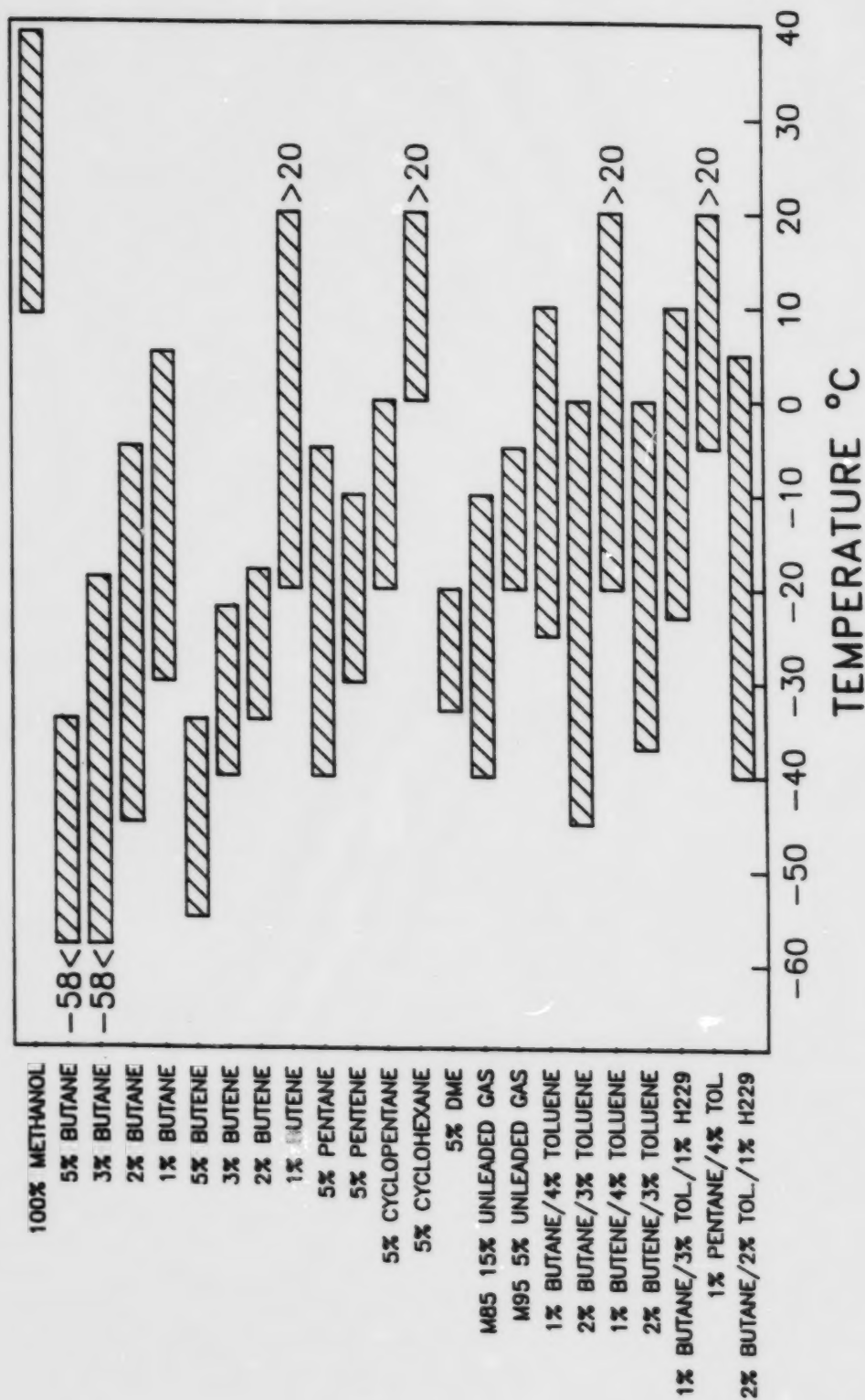
FLAMMABILITY

- Lower Limit $\leq 0^{\circ}\text{F}$ (-18°C)
- RVP ≤ 9 psi (?)





FLAMMABILITY LIMITS FOR METHANOL MIXTURES



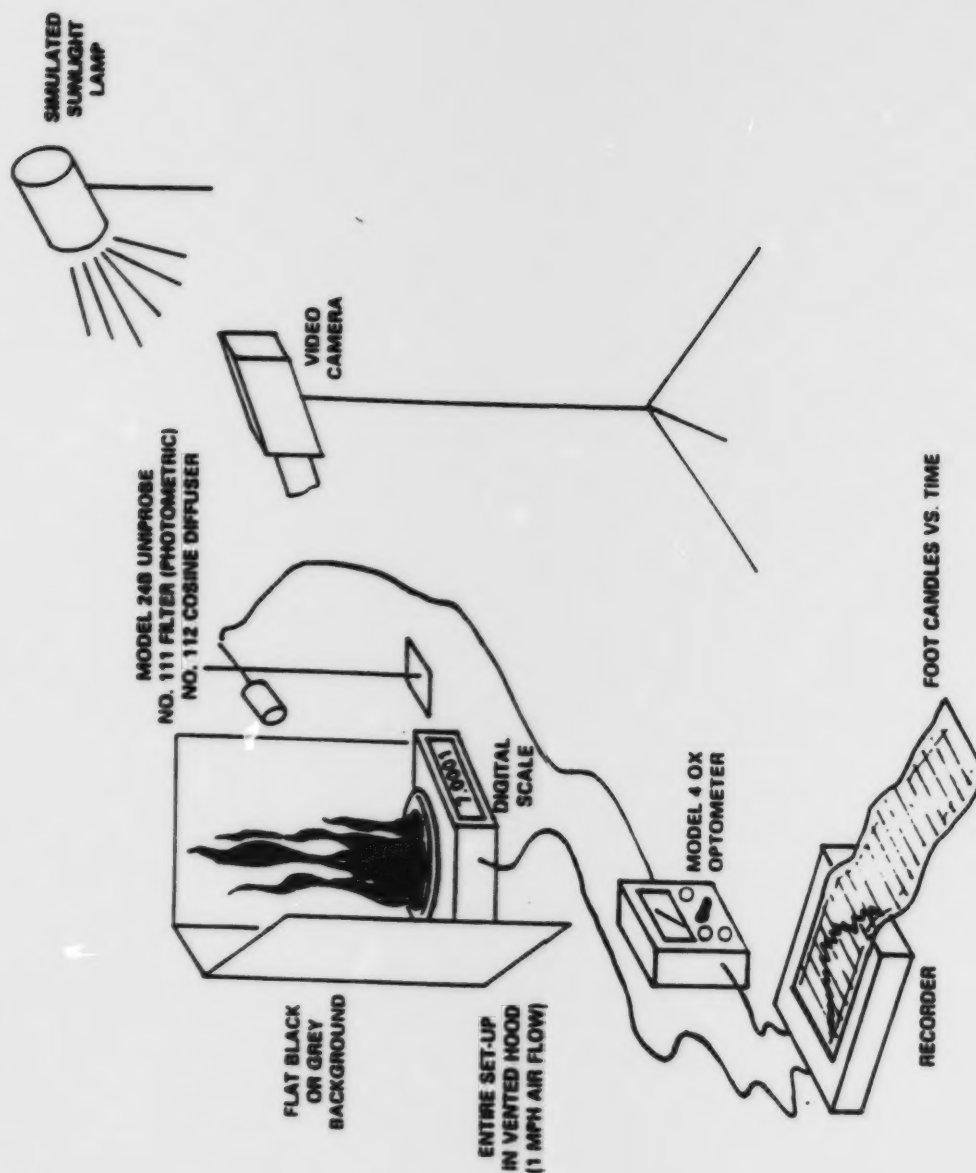
Additive in Methanol	Reid Vapor Pressure, (psi)
5% Butane	13.55
3% Butane	9.35
2% Butane	7.55
1% Butane	6.50
5% Butene	11.40
3% Butene	9.30
2% Butene	7.00
1% Butene	6.20

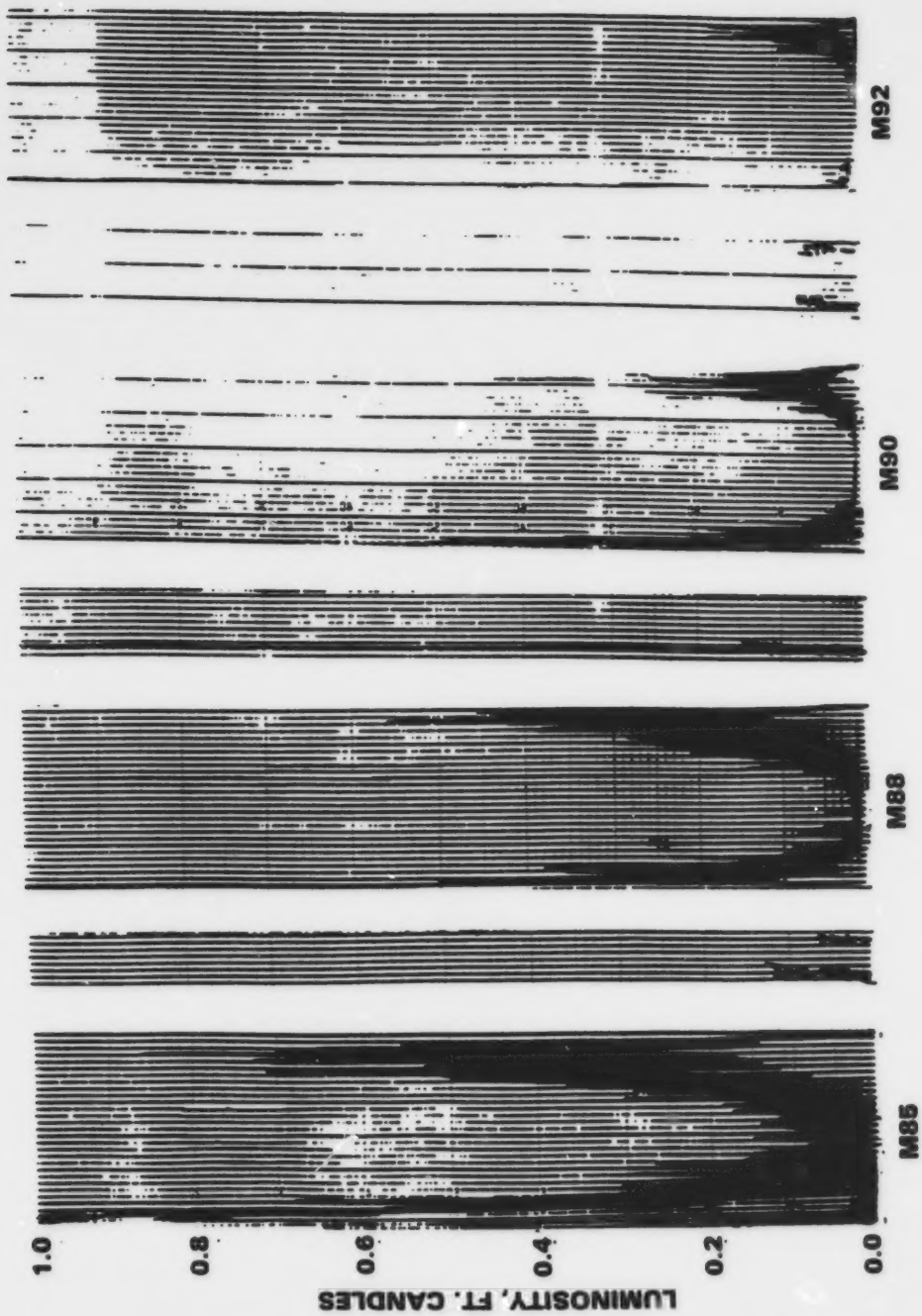
LUMINOSITY

Reference: Ethanol

Objective: Define minimum
acceptable luminosity







CONCLUSIONS

- **Lubricity:** Fuel Pump OK
U.C. Wear?
- **Flammability:** Seasonal-Regional
- **Luminosity:** M93
Education



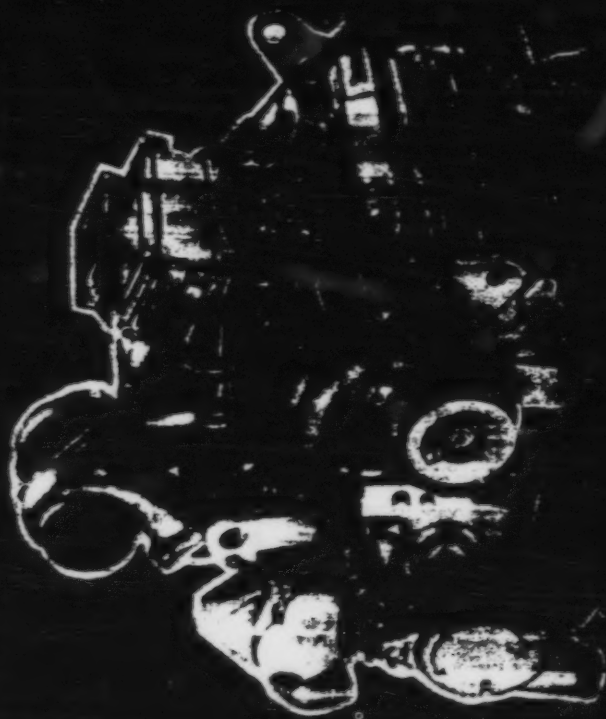
DDC METHANOL ENGINE DEVELOPMENT STATUS

S.P. Miller
Detroit Diesel Corporation

WINDSOR WORKSHOP

June 11-14, 1990
Toronto, Canada

6V-90TA METHANOL COACH ENGINE



METHANOL COACH ENGINE

HARDWARE CHANGES

SOLID STATE GLOW PLUG
CONTROLLER (DDEC CONTROLLED)

MAXI BY-PASS BLOWER & CONTROLLER
(DDEC CONTROLLED)

GLOW PLUG

EXHAUST

WATER PUMP

WATER PUMP

EXHAUST TURBO MATCH

EXHAUST CAM
SHAFTS AND
VALVES

6V-92 METHANOL EMISSIONS

	HC	NOx	CO	PART	ALDH
1991 STANDARDS	1.3	5.0	15.5	0.1	
DEMONSTRATED ENGINE-OUT	0.7	2.3	2.0	0.08	0.08
WITH OPTIONAL CATALYTIC CONVERTER	0.1	2.3	0.2	0.03	0.04

CATALYTIC CONVERTER

CERAMIC MONOLITH
9" O.D. x 6" LONG

9.65" DIA.

5" DIA.

METHANOL URBAN BUS DEMONSTRATION

54 BUSES AT 8 PROPERTIES

LOS ANGELES, CALIFORNIA	30
TRIBORO, NEW YORK	6
DENVER, COLORADO	5
MEDICINE HAT, ALBERTA	5
RIVERSIDE, CALIFORNIA	3
PHOENIX, ARIZONA	2
WINNIPEG, MANITOBA	2
GOLDEN GATE, CALIFORNIA	1



BUS DEMONSTRATIONS

OVER 1.7 MILLION MILES ACCUMULATED
THROUGH MAY, 1990.

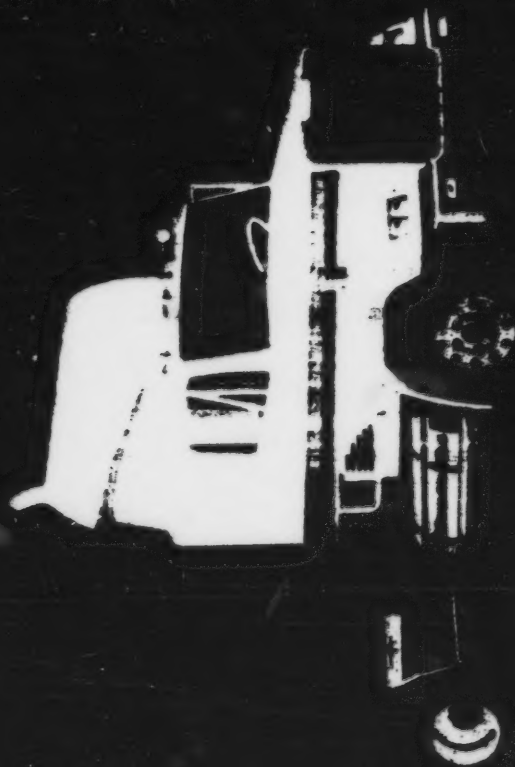
3 NEW METHANOL BUSES FOR MEDICINE HAT
ALBERTA CANADA IN SEPTEMBER, 1990.

50 SCHOOL BUSES IN CALIFORNIA IN 1990.

11 ETHANOL ENGINES FOR PEORIA,
ILLINOIS IN LATE 1990.

ONE 6L-71 BUS IN BOLOGNA ITALY
IN MID 1990

METHANOL TRUCK DEMONSTRATIONS



CALIFORNIA ENERGY COMMISSION

6V-92TA 350 HP CITY OF L.A.

6V-92TA 300 HP
PTL/GOLDEN STATE FOODS

6L-71TA 300 HP PTL/FEDERAL EXPRESS

SOUTHERN CALIFORNIA EDISON

6V-92TA 300 HP UTILITY TRUCK

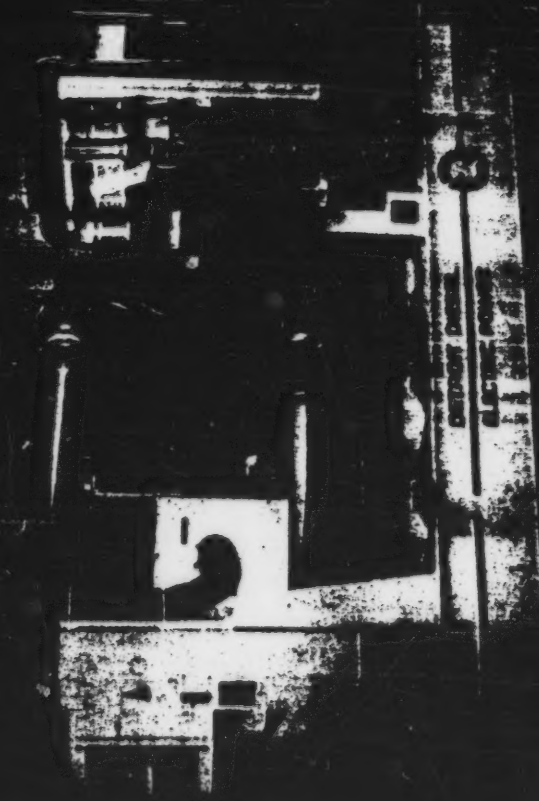
NEW YORK CITY SANITATION

6L-71TA 240 HP GARBAGE TRUCK

WASTE MANAGEMENT INC.

(2) 6L-71TA 240 HP GARBAGE TRUCKS

METHANOL GENERATOR SET PROGRAM



- LOW POWER 3V-927A
(260 HP @ 1500 RPM)
ON TEST AT VALLEY

- HIGH HP DEVELOPMENT
PROPOSAL APPROVED
BY SCAQMD WORK
BEGIN JUNE 1983

1110 SERIES
P10-031

6V-92 METHANOL ENGINE RELIABILITY SUMMARY

LOCATION	SAMPLE SIZE	TOTAL MILES ACCUMULATED	FEB. - APRIL, 1990	
			23:1	19:1
TRIBORO	6	422,410	89%	69%
RIVERSIDE	3	197,710	90%	90%
WINNIPEG	2	161,771	-	72%
MEDICINE HAT	5	131,958	96%	92%
DENVER	5	192,070	99%	94%
SCRTO	30	486,423	96%	95%
GOLDEN GATE	1	81,116	100%	-
PHOENIX	2	40,217	-	95%
TOTAL	54	1,713,676	94%	91%

6V-92 METHANOL ENGINE RELIABILITY & DURABILITY CONCERNS

CONCERN

GLOW PLUGS

**EXHAUST VALVE
SEAT WEAR**

**FUEL PUMP
GEAR WEAR**

STATUS

**SOLVED - HIGH COMPRESSION RATIO
REDUCES ON-TIME TO ACCEPTABLE LEVELS
FIELD DEMONSTRATION IN PROCESS.**

**POWDERED METAL VALVE SEAT INSERTS SHOW
SIGNIFICANT IMPROVEMENT. FIELD
DEMONSTRATION IN PROCESS.**

**RYTON MATERIAL SOLVES WEAR PROBLEM
FIELD DEMONSTRATION IN PROCESS.**

6V-92 METHANOL ENGINE FUEL INJECTOR RELIABILITY CONCERNS

CONCERN

SPRAY TIP HOLE
PLUGGING

STATUS

PROBLEM CAUSED BY THE REACTION
OF METHANOL WITH LUBE OIL.

SOLVED WITH A FUEL ADDITIVE.
SUCCESSFULLY TESTED IN-HOUSE.
FIELD DEMONSTRATION IN PROCESS.

FURTHER STUDY OF FUEL ADDITIVES AND
LUBE OIL FORMULATIONS IN PROCESS.

PLUNGER SCORING
AND SEIZING

CAUSED BY LACK OF LUBRICITY OF METHANOL
HARDWARE CHANGES, LUBRICITY ADDITIVES
AND LUBE OIL FORMULATION CHANGES
BEING PURSUED.

PLUNGER SCORING SUMMARY

OIL SQUIRTING-ROCKER ARMS

**HAVE PROVEN BENEFIT ON PLUNGER SEIZING
BEING IMPLEMENTED IN FIELD IN CONJUNCTION
WITH LUBRIZOL FUEL ADDITIVE**

LUBRICATING OIL

**FUEL ADDITIVE PERMITS USE OF MORE WEAR
PROTECTING LUBE OILS**

PLUNGER MODIFICATIONS

LAPPING SOLVES INFANT SCORING PROBLEM (BREAK-IN)

FUEL ADDITIVES

**LUBRIZOL ADDITIVE CONTAINS A LUBRICITY IMPROVER
ADDITIONAL LUBRICITY ADDITIVES BEING TESTED**

FIELD EXPERIENCE WITH LUBRIZOL FUEL ADDITIVE THROUGH MAY, 1990

SITE	NO. BUSES	NO. WEEKS	TOTAL MILES	NO. TIPS PLUGGED	PLUNGER LEAKS OR SEIZURES
TRIBORO	6	9	35,000	0	0
DENVER	5	9	39,000	0	0
PHOENIX	2	4	5,000	0	0
SCRTD	30	4	63,000	0	14

NOT CONFIRMED - MAY BE CLUTCH
NOT AT FULL STRENGTH

6V-92 METHANOL ENGINE STARTABILITY AND PERFORMANCE

STARTABILITY

BETTER THAN DIESEL

**NO PROBLEMS EXPERIENCED IN COLD
CLIMATE DEMONSTRATIONS**

ACCELERATION

0 - 10 MPH BETTER THAN DIESEL

≥10 MPH EQUAL TO DIESEL

METHANOL BUS DEMONSTRATED ENERGY CONSUMPTION

BEST MPG RATIO 2.35:1

**AVERAGE MPG RATIO FOR
PRE-PRODUCTION ENGINES 2.66:1**

RATIO IS DUTY CYCLE DEPENDENT

**DIESEL CONTROL ENGINES ARE AT
6-10 G/BHP-HR NOx**

METHANOL BUS ENGINE MAINTENANCE REQUIREMENTS

	<u>MILES</u>	<u>OR</u>	<u>MONTHS</u>
GLOW PLUGS - REPLACE	50K		12
INJECTORS - CLEAN TIPS	50K		12
- CHANGE OUT	100K		24
BYPASS CONTROL COMPONENTS			
PWM SOLENOID VALVE - REPLACE	50K		
FEEDBACK POTENTIOMETER - REPLACE	100K		
AIR PRESSURE REGULATOR FILTER - CLEAN			
CHANGE OIL & FILTER			PER MANUFACTURER'S RECOMMENDATIONS
CHANGE FUEL FILTERS - 1st. CHANGE	1,000		
- THEREAFTER	6,000		

A REMANUFACTURING EXCHANGE PROGRAM WILL BE ESTABLISHED.
OIL MUST ALSO BE CHANGED IF CONTAMINATED WITH FUEL OR FUEL ADDITIVES.
THIS COMPONENT IS SUPPLIED BY THE U.S. MANUFACTURER.

DDC RECOMMENDED METHANOL FUEL SPECIFICATION

METHANOL

PURITY, VOLUME %

98.0 MINIMUM

OTHER ALCOHOLS, VOLUME %

2.0 MAXIMUM

PETROLEUM PRODUCT
DERIVATIVES, VOLUME %

1.0 MAXIMUM

TOTAL GUMS, AS PER ASTM D-381

4 PPM MAXIMUM

ACIDITY (AS FORMIC ACID), VOLUME %

.003 MAXIMUM

TOTAL PARTICULATES AS PER ASTM D2276

2 PPM MAXIMUM

CONCLUSIONS

ENGINE-OUT EMISSION LEVELS HAVE BEEN DEMONSTRATED THAT MEET THE 1991 EPA STANDARDS.

SOLUTIONS TO INJECTOR PROBLEMS ARE BEING DEMONSTRATED IN THE FIELD.

THE 6V-92TA METHANOL BUS ENGINE WILL BE AVAILABLE IN JANUARY, 1991 AT TRANSIT RATINGS OF 253 AND 277 HP.

A CATALYTIC CONVERTER WILL BE OFFERED AS AN OPTION FOR EVEN LOWER EMISSIONS.

FINAL FUEL AND LUBE OIL SPECS ARE BEING ESTABLISHED.

CONCLUSIONS (Continued)

STARTABILITY AND DRIVEABILITY ARE EQUAL TO OR BETTER THAN DIESEL.

THE GOAL OF ENERGY CONSUMPTION EQUIVALENT TO DIESEL HAS NOT YET BEEN DEMONSTRATED IN THE FIELD.

MORE PREVENTATIVE MAINTENANCE IS REQUIRED THAN DIESEL.

TRAINING IN MAINTENANCE, CONTROL SYSTEM TROUBLE SHOOTING AND HANDLING OF METHANOL IS IMPORTANT.

THE TECHNOLOGY IS MORE COSTLY THAN DIESEL, BUT NOT MORE COSTLY THAN OTHER "CLEAN" ALTERNATIVES.

**1990 WINDSOR WORKSHOP
ON ALTERNATIVE FUELS**

**TECHNICAL AND OPERATIONAL
SUMMARY OF
PROJECT MILE**

SYPHER:MUELLER International Inc.

OBJECTIVE

**TO DEMONSTRATE THE VIABILITY OF METHANOL AS
AN ALTERNATIVE FUEL FOR CANADIAN TRUCK AND
BUS FLEETS, ACCOUNTING FOR ALL ASPECTS OF
FLEET OPERATION INCLUDING TECHNICAL,
ECONOMIC AND SOCIAL FACTORS.**

PROJECT MILESTONES

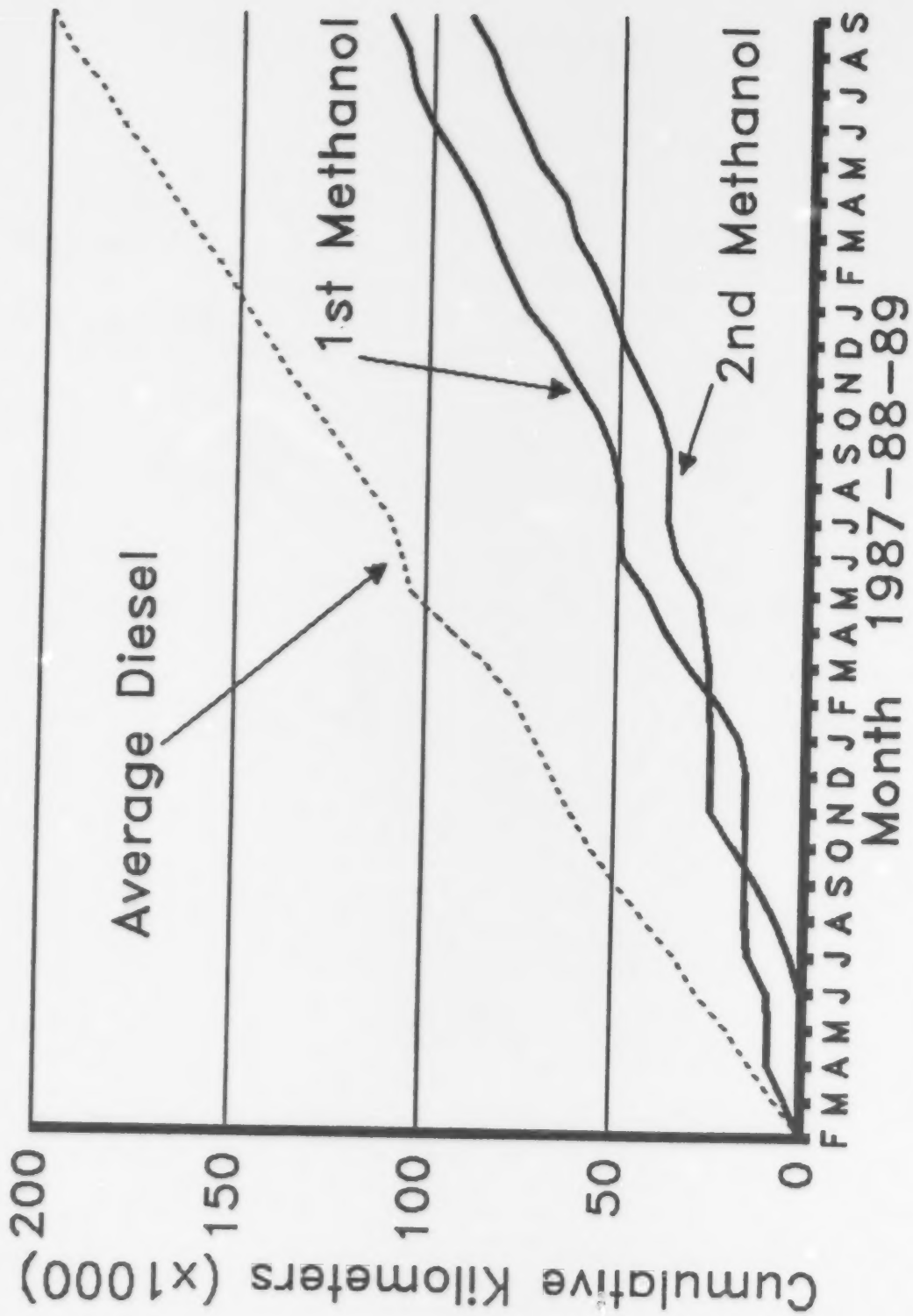
MARCH, 1985:	CONTRACT AWARD
NOVEMBER, 1986:	START WINNIPEG OPERATIONS
FEBRUARY, 1987:	START MEDICINE HAT OPERATIONS
NOVEMBER, 1987:	START WILLIAMS OPERATIONS
JUNE, 1988:	START CITY OF VANCOUVER OPERATIONS
JUNE, 1989:	CLOSE DOWN WILLIAMS OPERATIONS
DECEMBER, 1989:	NEW MEDICINE HAT BUSES
DECEMBER, 1990:	CLOSE DOWN WINNIPEG AND VANCOUVER

DISTANCES ACHIEVED
TO END OF 1989

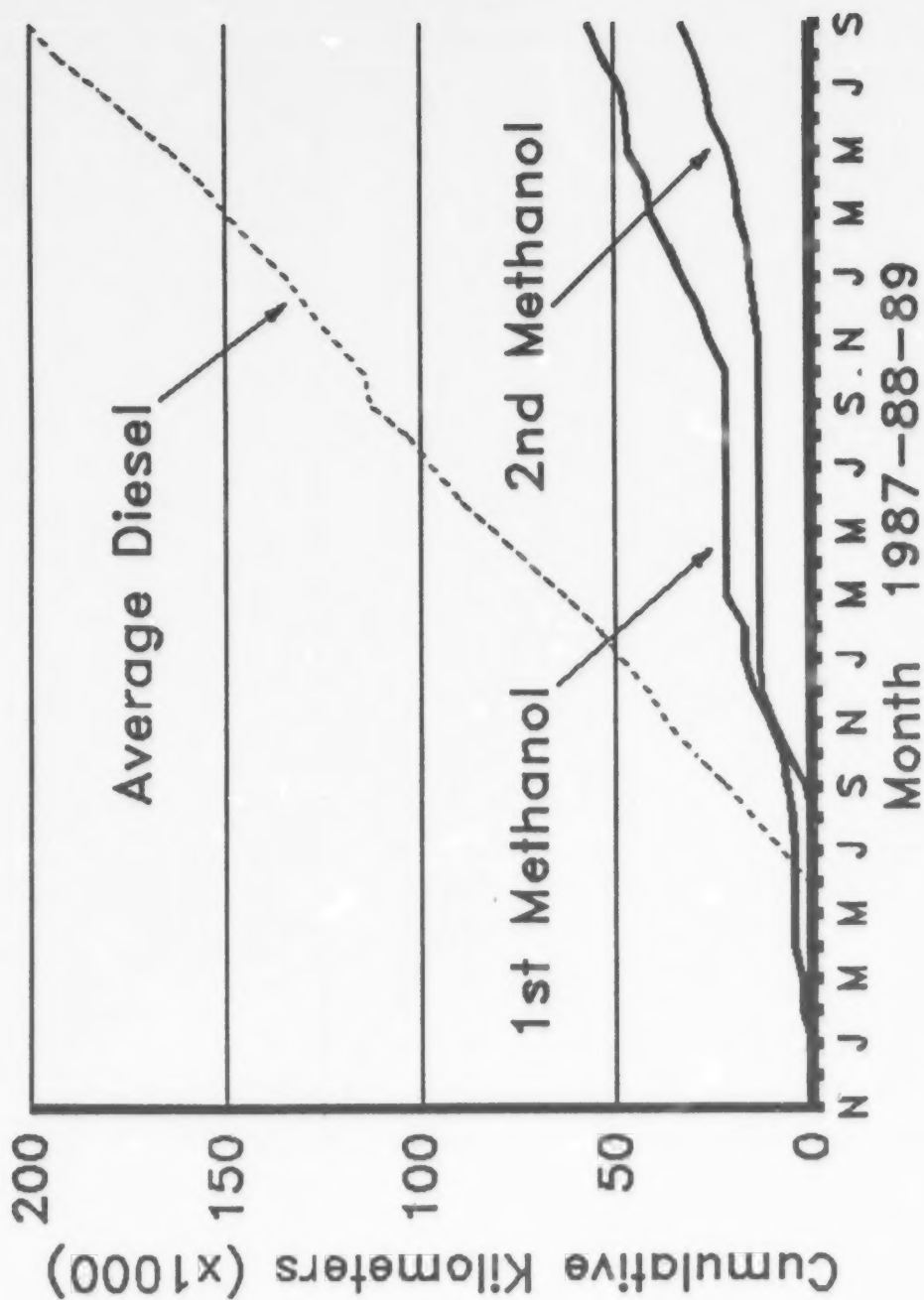
FOUR BUSES - DETROIT DIESEL: 350,000 KM

TWO TRUCKS - CATERPILLAR: 600,000 KM

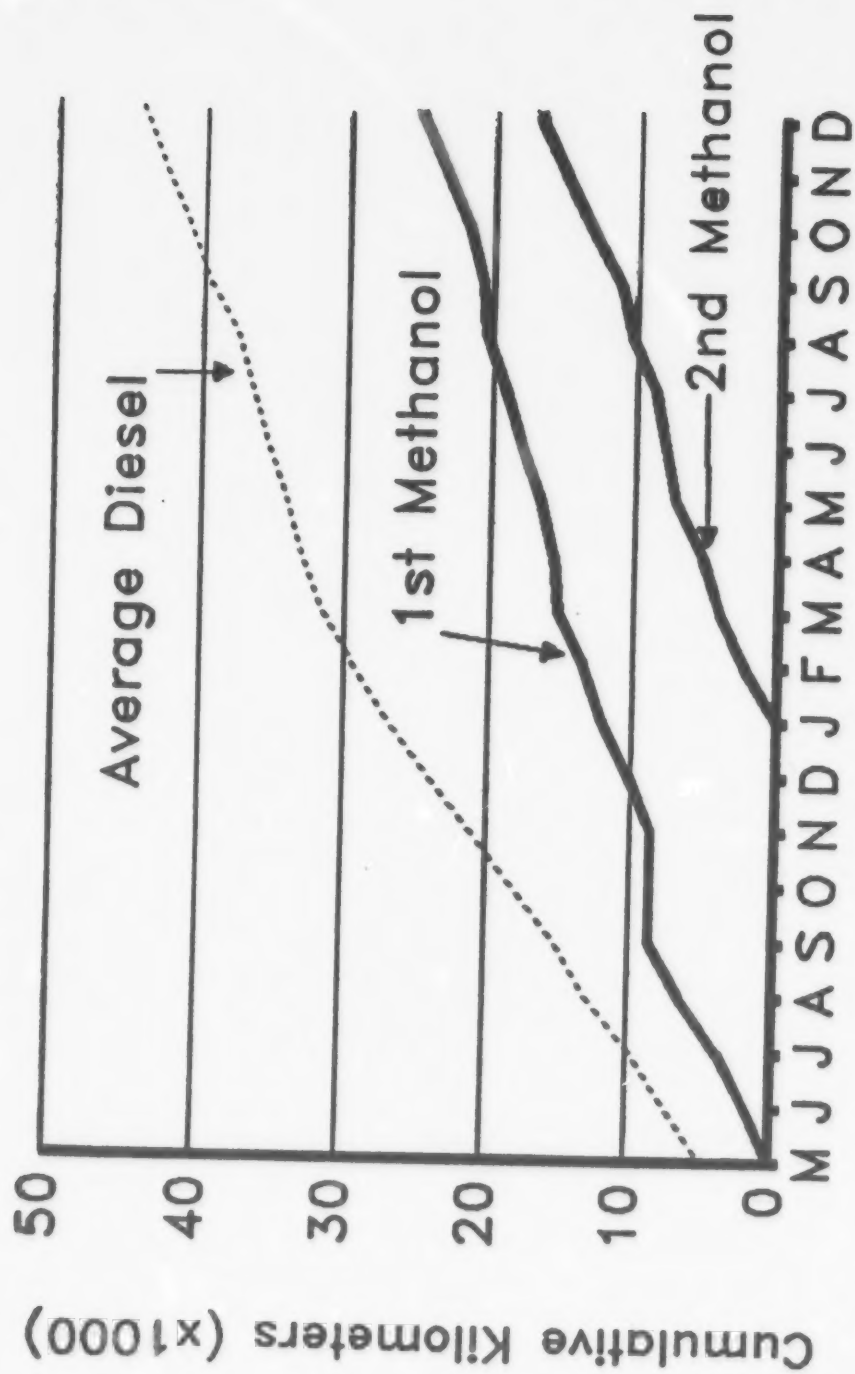
TWO TRUCKS - CUMMINS: 40,000 KM



Cumulative Kilometers: Winnipeg Buses

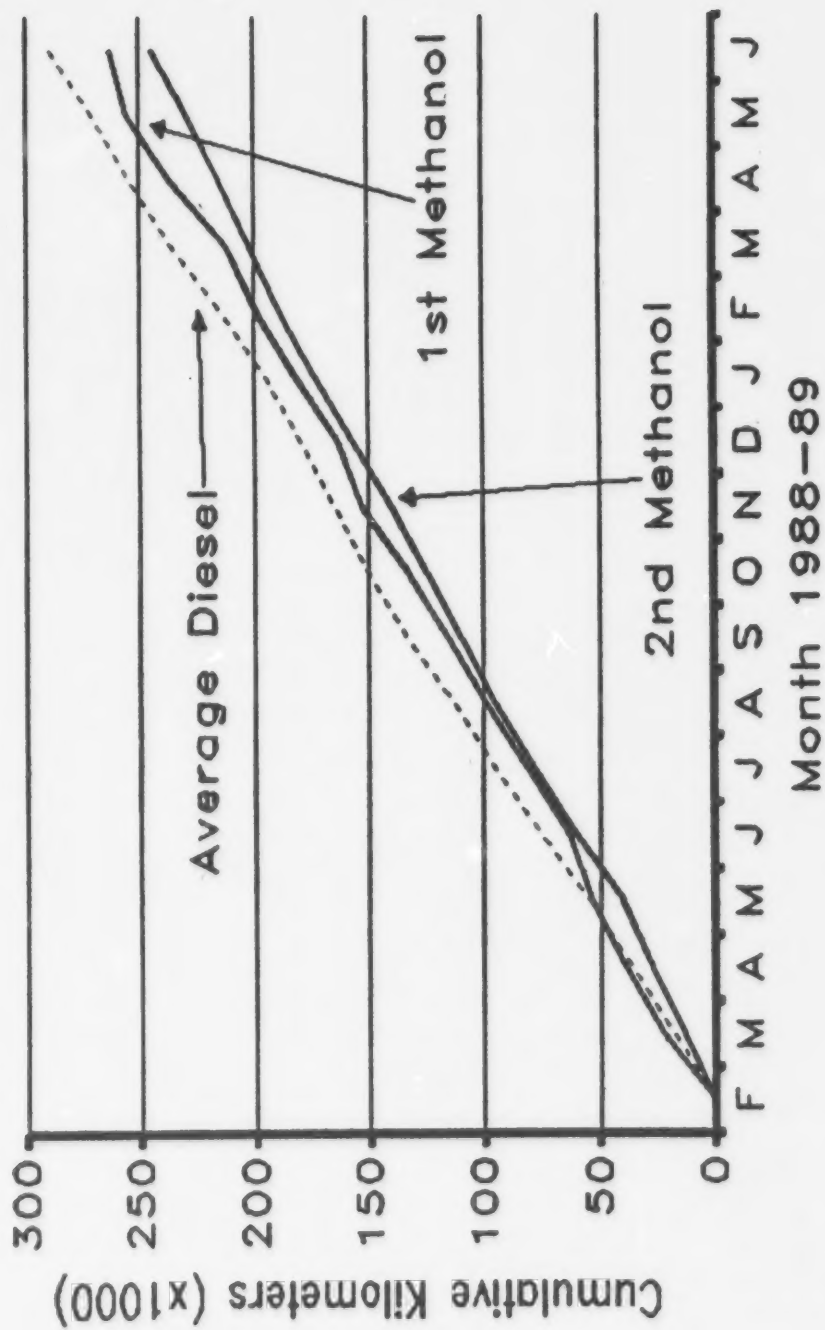


Cumulative Kilometers: Medicine Hat Buses



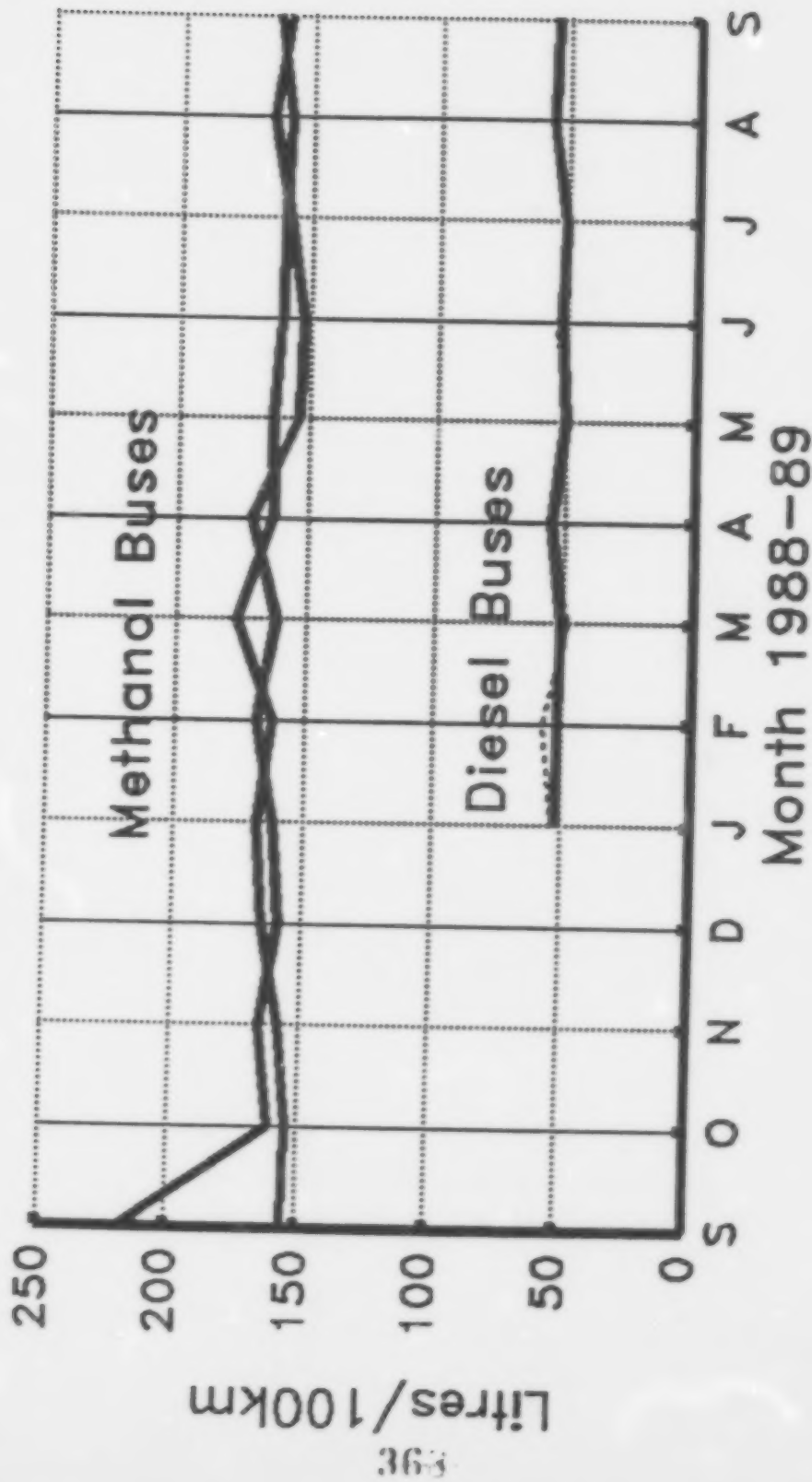
Month: 1988-89

Cumulative Kilometers: City of Vancouver Trucks

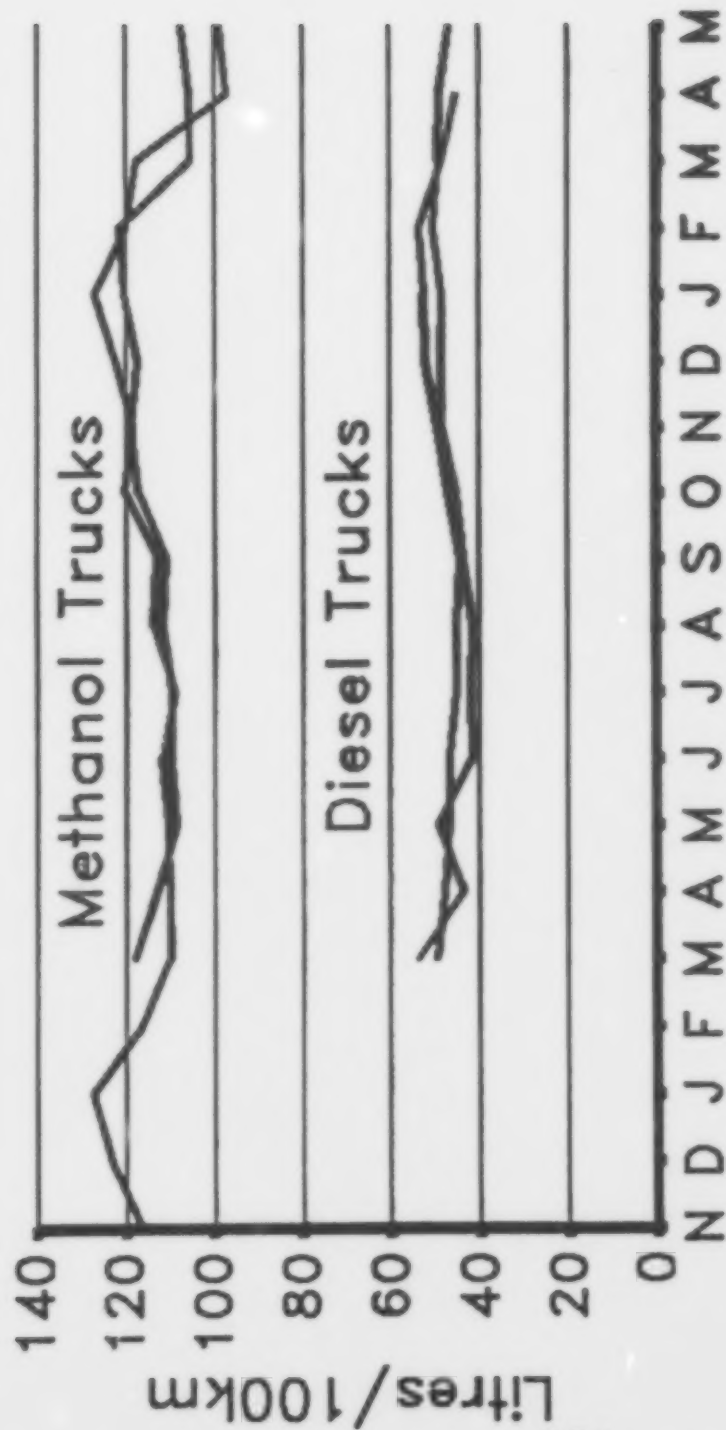


Cumulative Kilometers: Williams Trucks

RATIO RANGE: 2.6 TO 2.8:1



Monthly Fuel Consumption; Winnipeg Buses



Monthly Fuel Consumption: Williams Trucks

AVERAGE RATIO: 2.4 TO 1

Fuel Consumption: Cummins Trucks

Truck No.	Consumption (Litres/100km)	
	Before March 1989	After March 1989
M874	151.7	184.3
M875	-	184.8
D878	62.7	71.4
D879	70.0	88.9
Methanol Average	151.7	184.6
Diesel Average	66.3	79.4
Methanol/Diesel Ratio	2.29:1	2.32:1

VEHICLE PERFORMANCE

ALL - ROUND PERFORMANCE AND DRIVEABILITY

EQUAL TO DIESEL VEHICLES.

SERVICING AND MAINTENANCE

WINNIPEG TRANSIT: ALL 'IN-HOUSE'

MEDICINE HAT TRANSIT: FLEET AND DEALER

WILLIAMS MOVING: DEALER

CITY OF VANCOUVER: DEALER

ALL FLEETS DO THEIR OWN FUELLING.

ONE EXTERNAL FUELLING STATION.

UNRESOLVED MECHANICAL PROBLEMS

GLOW PLUGS

- **ELIMINATE OR DEVELOP SPECIAL TYPES**

VALVE SEAT WEAR

- **IMPROVE MATERIALS**

FUEL INJECTORS

- **WATER CONTENT**
- **FUEL FILTRATION**
- **ADDITIVES**

LONG TERM WEAR

**CATERPILLAR ENGINES SHOWED NO GREATER
WEAR THAN A SIMILAR MILEAGE DIESEL. EXCEPT
FOR VALVE SEATS AND MINOR PISTON CRACKS.**

CONCLUSION

**METHANOL FUEL IS NOT AS INHERENTLY SAFE AS
DIESEL, BUT PROPER PERSONNEL TRAINING AND
THE USE OF APPROPRIATE EQUIPMENT CAN
PROVIDE ACCIDENT FREE OPERATIONS.**

CONCLUSION

**NEW MAINTENANCE SKILLS WERE REQUIRED TO
KEEP THE PROJECT VEHICLES OPERATIONAL,
PARTICULARLY REGARDING ELECTRONIC
TECHNOLOGY, BUT THE SAME APPLIES TO MANY
MODERN DIESEL ENGINES.**

CONCLUSION

**FUEL DISTRIBUTION AND STORAGE IS NOT A
PROBLEM WITH A DEDICATED SYSTEM BUT MAY
GIVE TROUBLE IN AN INTERIM SITUATION.**

CONCLUSION

**ENERGY - BASED FUEL CONSUMPTION IS NOT YET
EQUIVALENT TO DIESEL.**

CONCLUSION

**EQUIVALENT RELIABILITY TO DIESEL ENGINES IS
NOT YET GUARANTEED, BUT STANDARDS ARE
CONSTANTLY IMPROVING AND NO MECHANICAL
PROBLEMS APPEAR TO BE INSURMOUNTABLE.**

CONCLUSION

**TO GAIN ACCEPTANCE AMONG FLEET USERS,
PARTICULARLY BUS FLEETS, METHANOL ENGINES
MUST DEMONSTRATE EXHAUST ALDEHYDE
OUTPUTS NEAR TO THOSE OF COMPETITIVE DIESEL
ENGINES.**

CONCLUSION

**METHANOL IS A VIABLE REPLACEMENT FOR DIESEL
FUEL IN CANADIAN HEAVY DUTY VEHICLE FLEETS IN
THE NEAR AND MEDIUM TERM, FROM A TECHNICAL
POINT OF VIEW.**

CALIFORNIA ALTERNATIVE FUELED TRUCK DEMONSTRATION PROGRAM

**Douglas D. Lowell
Michael D. Jackson
Acurex Corporation**

**Cindy A. Sullivan
California Energy Commission**

Windsor Workshop on Alternative Fuels

June 13, 1990

PROJECT SPONSORS

- **California Energy Commission**
- **South Coast Air Quality Management District**

OBJECTIVES

- **Demonstrate clean-fueled heavy-duty engines in a wide variety of trucking applications in California**
- **Quantify air quality benefits of clean-fueled vehicles**
- **Assess truck performance**
 - **Fuel economy**
 - **Power, acceleration, responsiveness**
 - **Reliability**
 - **Durability**
- **Provide manufacturers with field demonstration opportunity and a chance to improve their technology**
- **Enable host sites to demonstrate cooperation with efforts to clean up the environment**

SCOPE OF WORK

- **Task 1: Engines and Test Vehicles**
- **Task 2: On-Road Vehicle and Data Collection Program**
- **Task 3: Fuel Facilities**
- **Task 4: Training and Public Relations Activities**
- **Task 5: Vehicle Maintenance, Cost and Operation**
- **Task 6: Emissions Testing**
- **Task 7: Data Analysis and Dissemination**

SITE SUMMARY

Site Number	Site Name	Site Location	Truck Type	Engine Manufacturer & Model	OEM Model	Fuel Type
1	City of L.A. - Asphalt Plant	Los Angeles	Dump	Cummins L10	Peterbilt 379	M+A
2	City of L.A. - Hyperion	Los Angeles	Sludge hauler	DDC 6V-92	GMC General	M100
3	City of Glendale	Glendale	Refuse hauler	Cat 3306	Peterbilt 320	M100
4	Industrial Freight	Valencia	Tractor/trailer	TBD	International 8100	CNG
5	Golden State Foods	Pasadena	Tractor/trailer	DDC 6V-92	Freightliner	M100
6	Federal Express	Los Angeles	Tractor/trailer	DDC 6-71	Freightliner	M100
7	SCE	Pomona	Flat bed utility	DDC 6V-92	Volvo/White/Autocar	M85
8	Arrowhead	Los Angeles	Bottled water delivery	Ford 6.6L-MX	Ford F700	M85
9	City of South Lake Tahoe	South Lake Tahoe	Dump truck	Navistar CT-466	International	M100
10	CNG Site	TBD	TBD	TBD	TBD	CNG
11	Waste Management	Baldwin Park	Refuse hauler	DDC 6-71	Volvo/White	M100

8160-0072-M

ENGINE MANUFACTURER PARTICIPATION

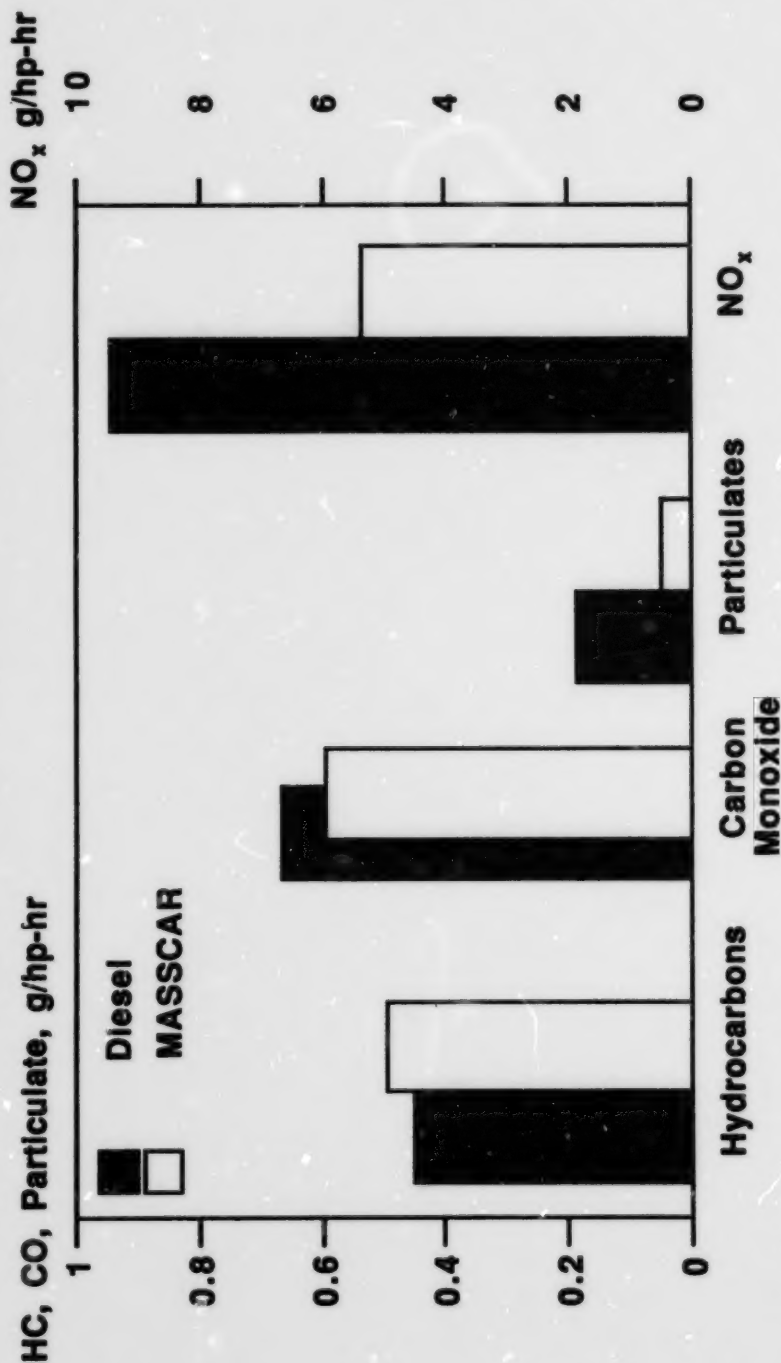
- **Caterpillar Inc.**
- **Cummins Engine Company, Inc.**
- **Detroit Diesel Corporation**
- **Ford**
- **Navistar International Transportation Corporation**

CATERPILLAR 3306 DITA METHANOL ENGINE

- Glow-plug-assisted ignition—glow plugs operate 100% of the time, with current varying with engine operating requirements
- Caterpillar laboratory test results
 - Power objective (245 hp at 2200 rpm) achieved
 - Brake specific energy consumption similar to 3306 DITA diesel
 - 50-hr cyclic durability test completed with no component failures
- Fuel-injection pump capacity increased to account for lower energy density of methanol fuel
- Supplemental lubrication supply installed for fuel pump plungers and barrels

HEAVY-DUTY VEHICLE EMISSIONS

MASSCAR, EIGHT-MODE CHASSIS TEST



Note: Preliminary data. Diesel is average of three vehicles. MASSCAR CR-23:1, Timing - 1.500

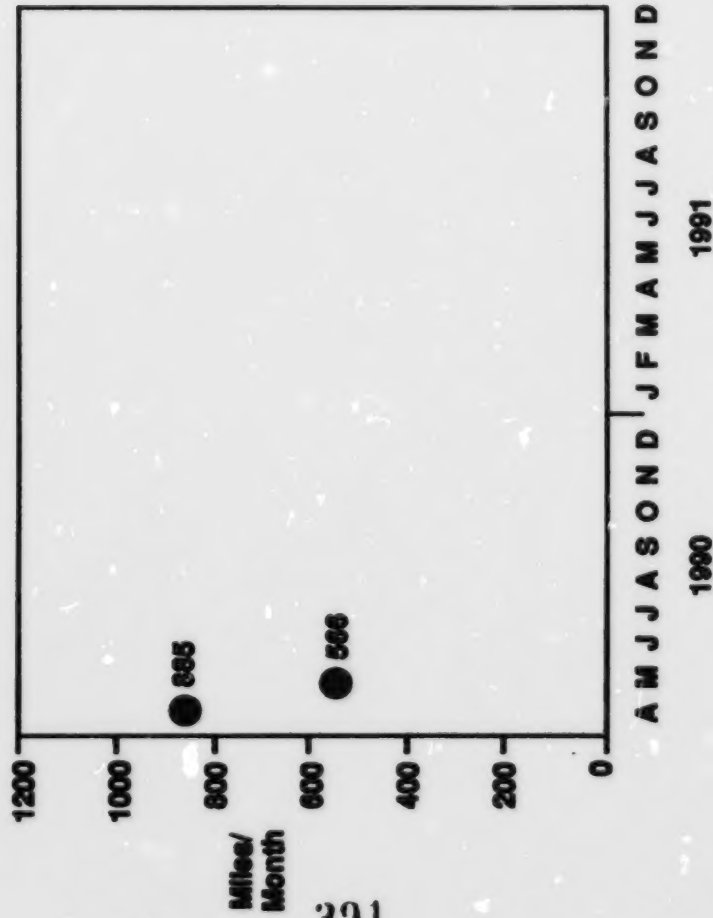
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CITY OF GLENDALE OPERATING RESULTS FOR APRIL AND MAY

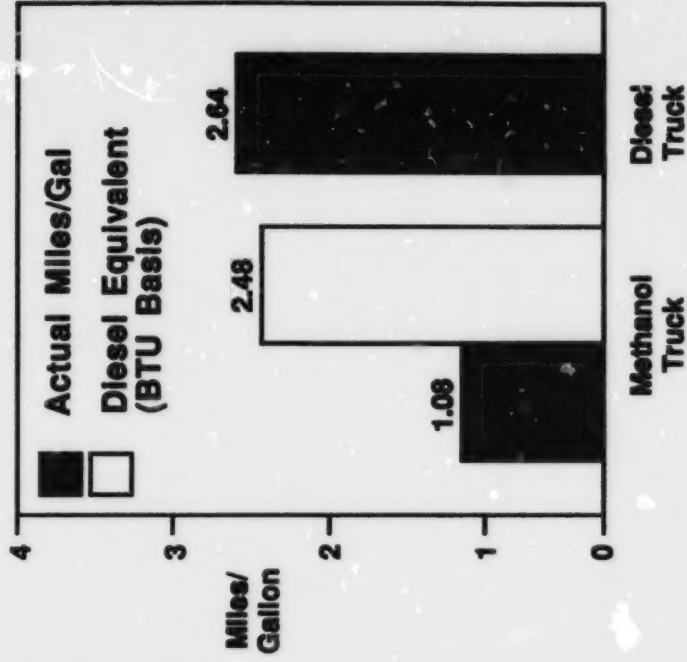
	Methanol (Unit No. 7238)	Diesel (Unit No. 7246)
Miles	1,451	1,746
Engine hours	198	263
Fuel economy (ml/gal)	1.08	2.64
Diesel-equivalent fuel economy (ml/gal)	2.48	N/A
Uptime (%)	86	100

CITY OF GLENDALE

Monthly Mileage



Fuel Economy



CUMMINS L10 METHANOL ENGINE

- **Using 5-percent Avocet cetane improver**
- **Engine modifications include changes to fuel pump, camshaft, and fuel injectors**
- **Field hardware changes include:**
 - **Recalibration of fuel pump**
 - **Redesign of injector cups**
 - **Installation of hot-start kit**

FORD 6.6L MX METHANOL ENGINE

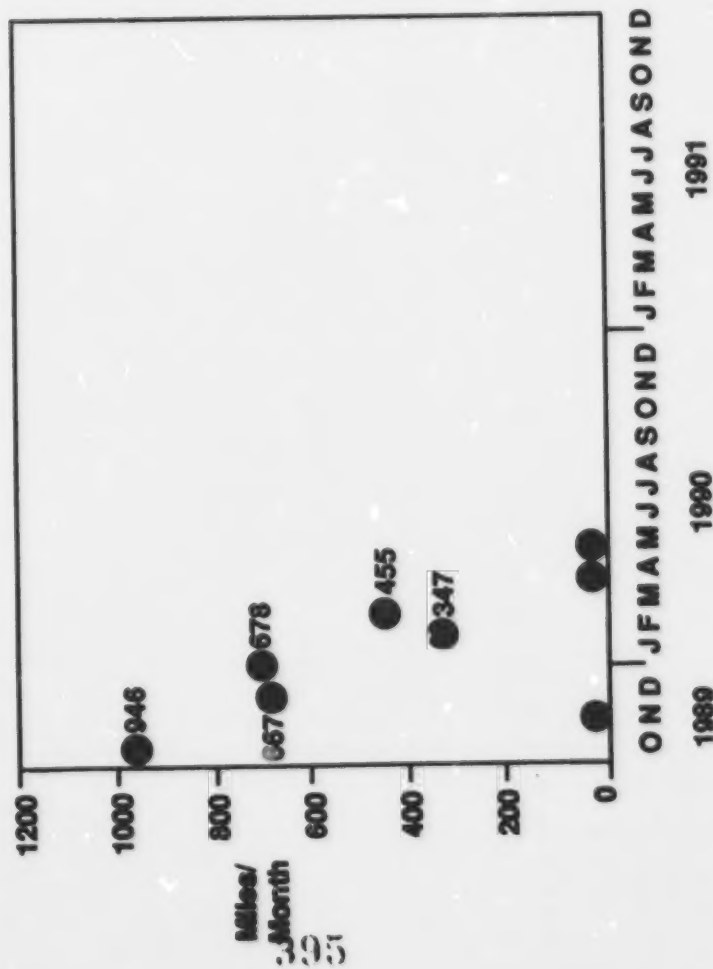
- Developed using Ford's experience in light-duty methanol fleet demonstrations
- Uses M85 fuel
- Spark-ignited, naturally aspirated engine rated 170 hp at 2600 rpm
- Compression ratio 11.3:1
- Catalyst will be used to reduce emissions
- 300-hr durability test resulted in no failure-related downtime

CITY OF LOS ANGELES - ASPHALT PLANT OPERATING RESULTS SINCE OCTOBER 1989

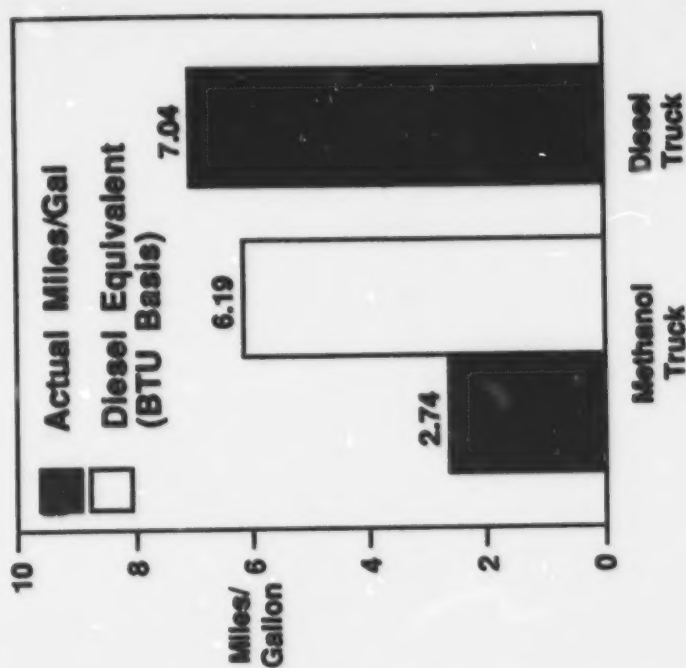
	Methanol (Truck No. 23444)	Diesel (Truck No. 23443)
Miles	3,560	13,635
Engine hours	245	1,936
Fuel economy (ml/gal)	2.74	7.04
Diesel-equivalent fuel economy (ml/gal)	6.19	N/A
Uptime (%)	24	87

CITY OF LOS ANGELES - ASPHALT PLANT

Monthly Mileage



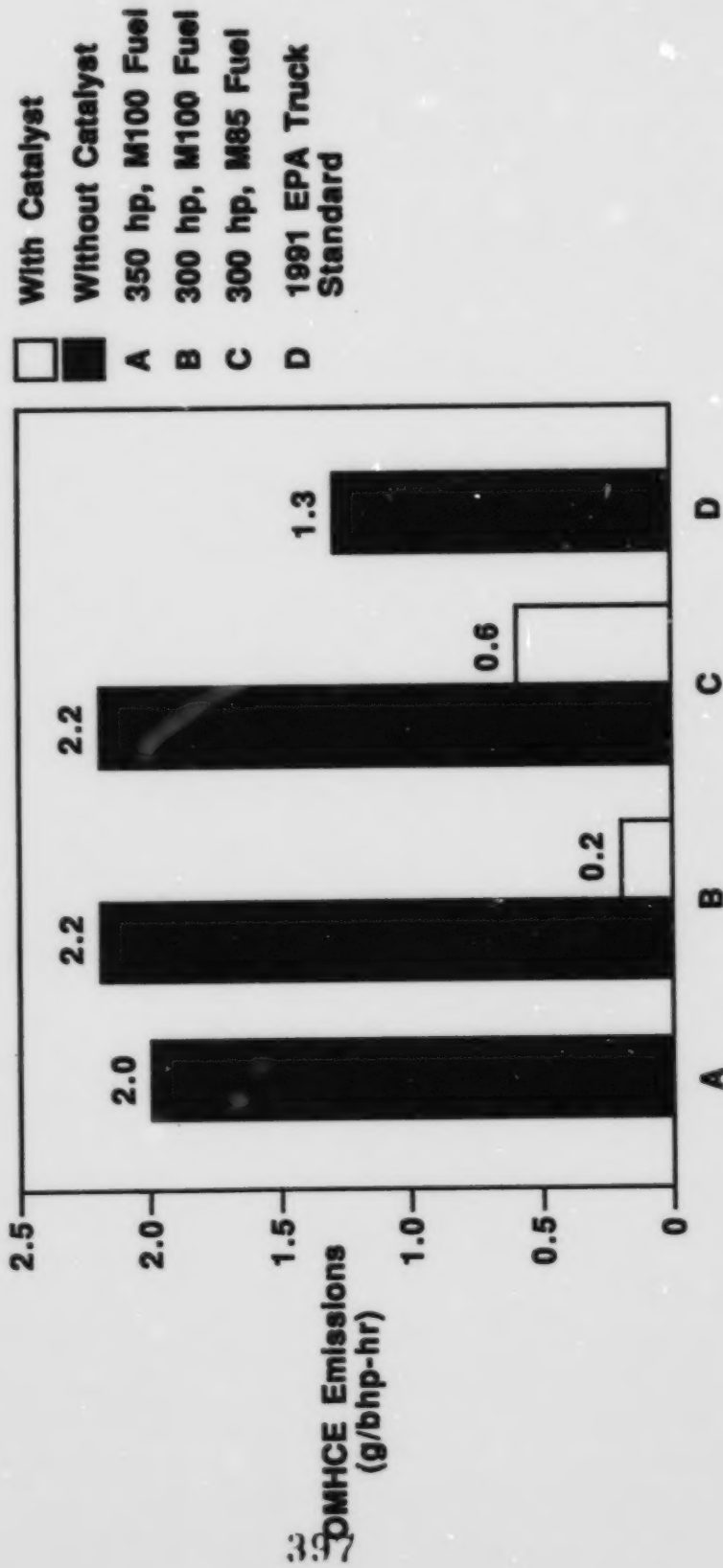
Fuel Economy



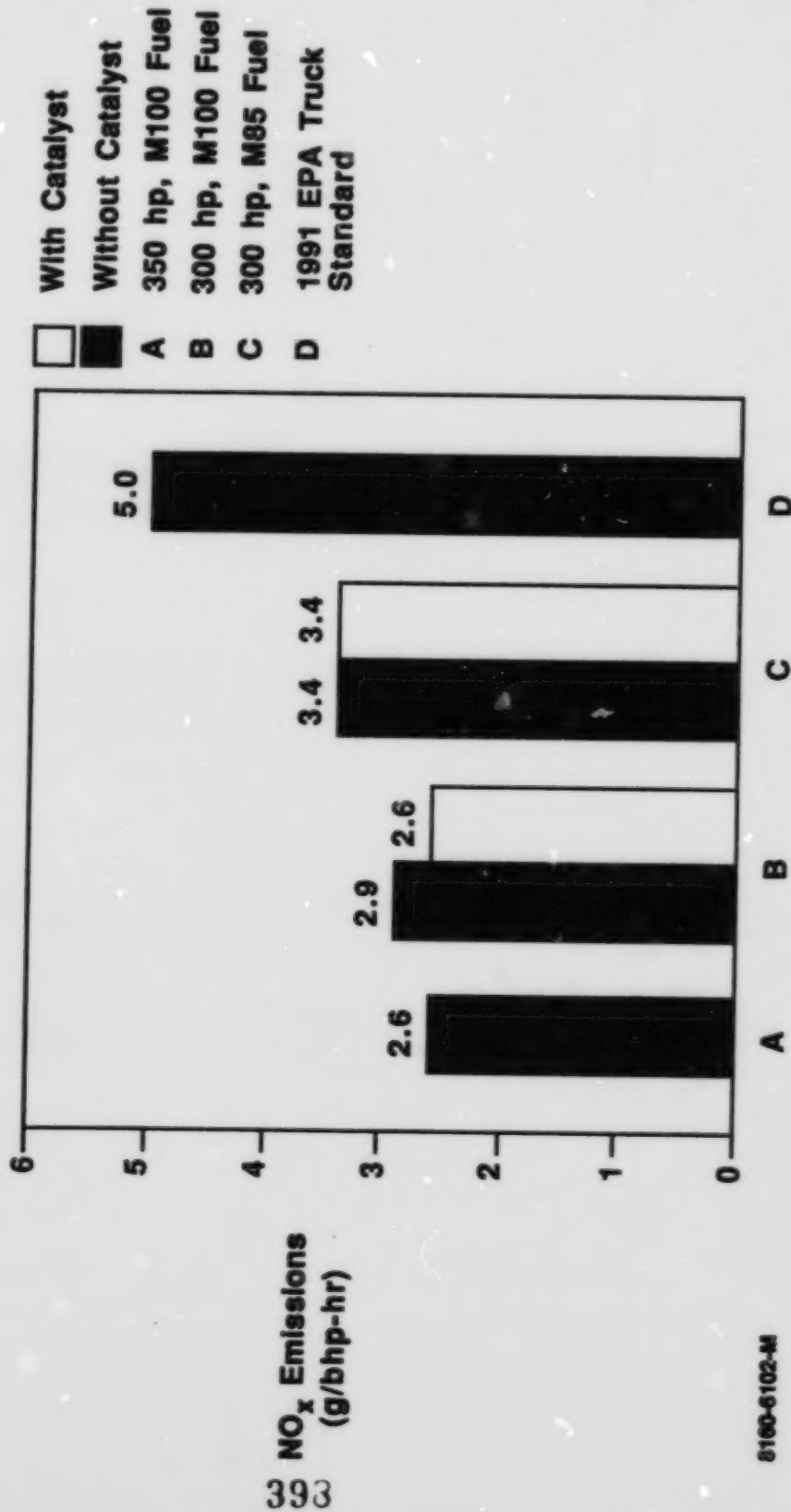
DETROIT DIESEL CORPORATION 6V-92TA and 6-71 METHANOL ENGINES

- 23:1 compression ratio
- Glow-plugs used only for starting and warm-up
- Bypass blower controls air/fuel ratio

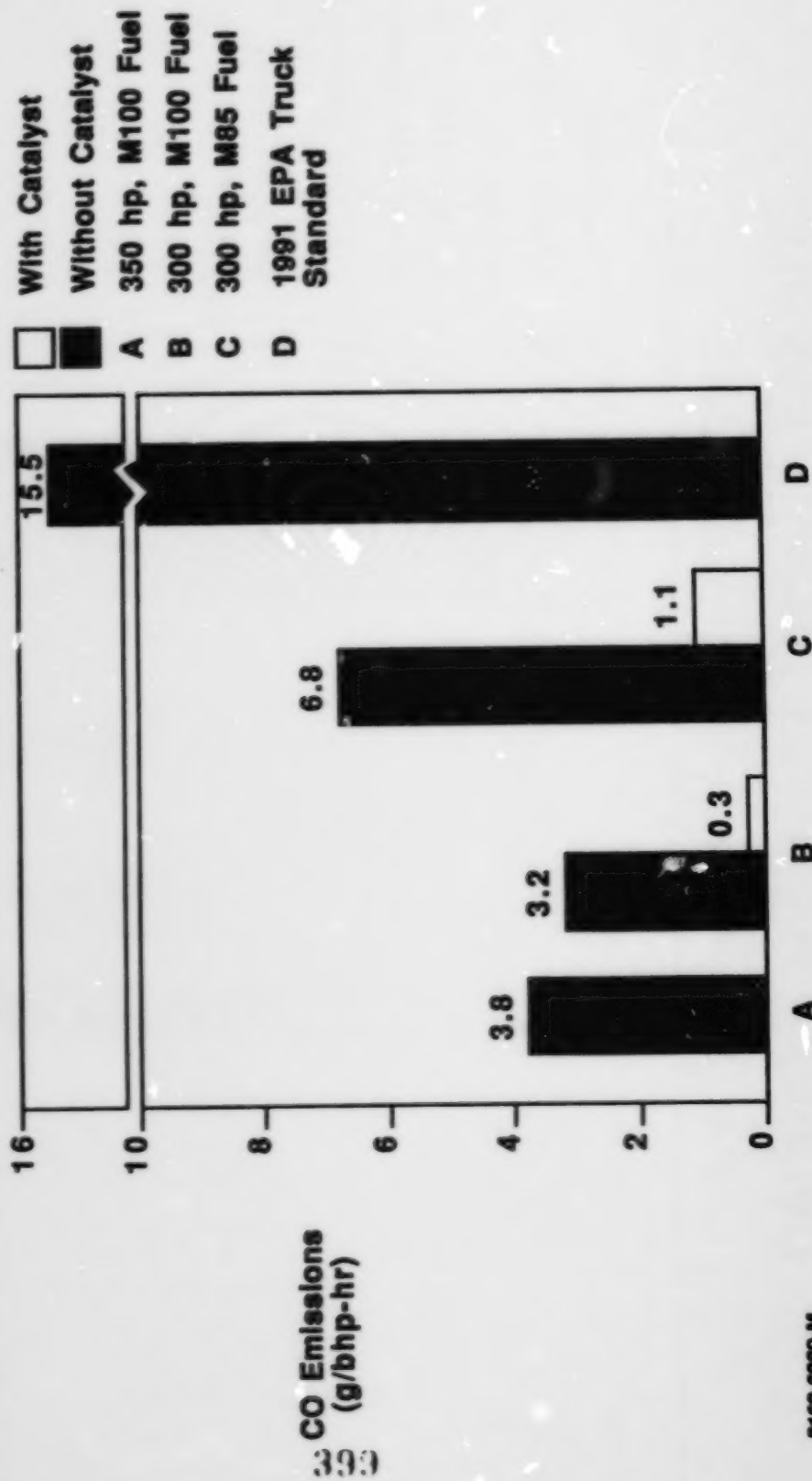
6V-92 TA DETROIT DIESEL ENGINE OMHCE EMISSIONS



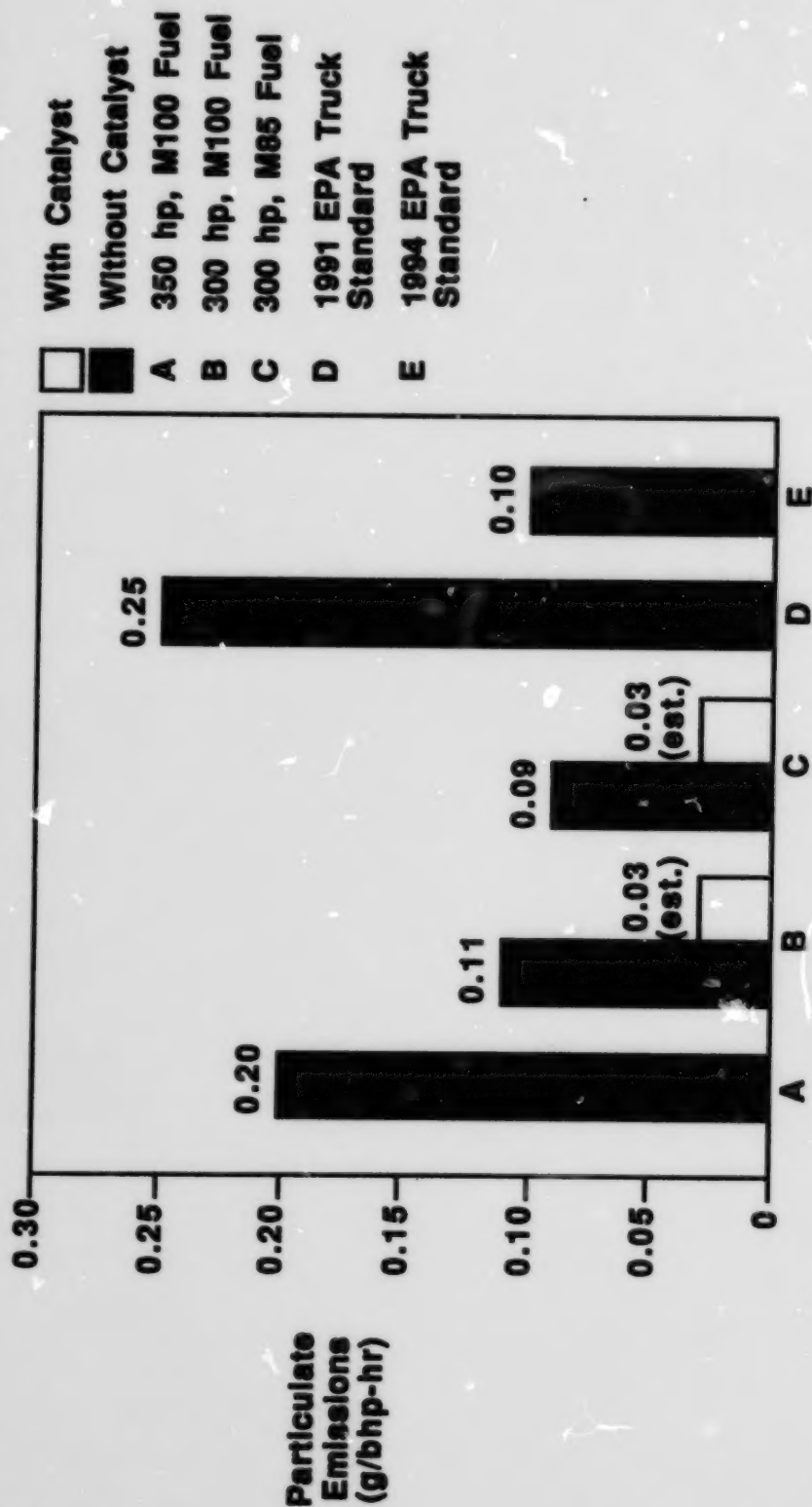
6V-92 TA DETROIT DIESEL ENGINE NO_x EMISSIONS



6V-92 TA DETROIT DIESEL ENGINE CO EMISSIONS



6V-92 TA DETROIT DIESEL ENGINE PARTICULATE EMISSIONS



WASTE MANAGEMENT

- DDC completed conversion of two new Volvo/White chassis for operation with 6-71 methanol engines; trucks have been driven to Volvo plant in Ohio for inspection and will be shipped to California
- Refuse packer body installation will be underway in California in late June 1990; trucks will enter service in July/August 1990
- M100 fuel will be obtained from Penske Truck Leasing facility in the City of Industry

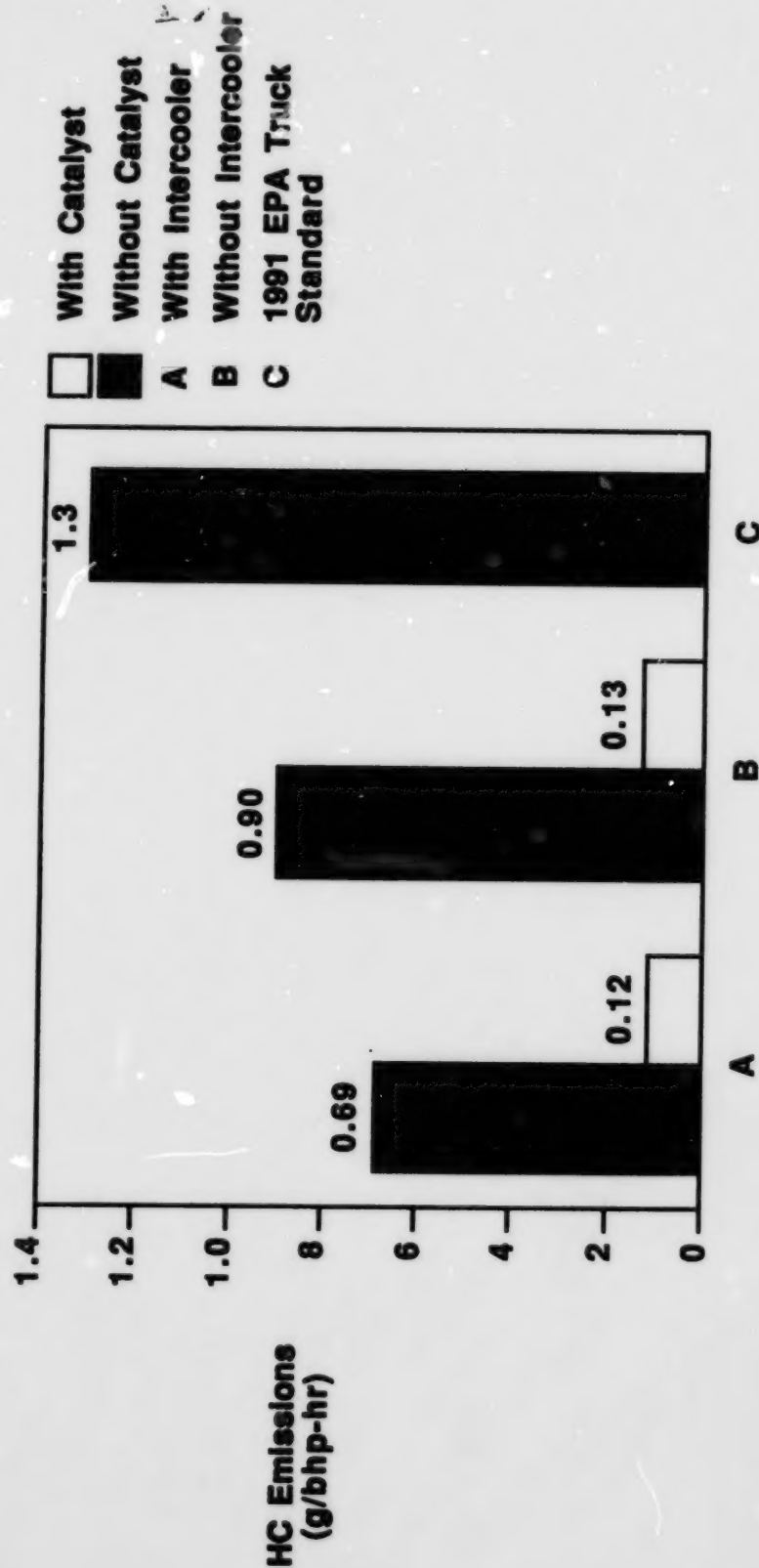
ARROWHEAD DRINKING WATER COMPANY

- **Ford 6.6L MX methanol engine installation in first Arrowhead truck nearly complete**
- **First vehicle will enter service July 1990**
- **Modification of second truck contingent upon successful performance of first; criteria for success to be defined**
- **Trucks will obtain M85 fuel from retail fuel station near Arrowhead base in Los Angeles**

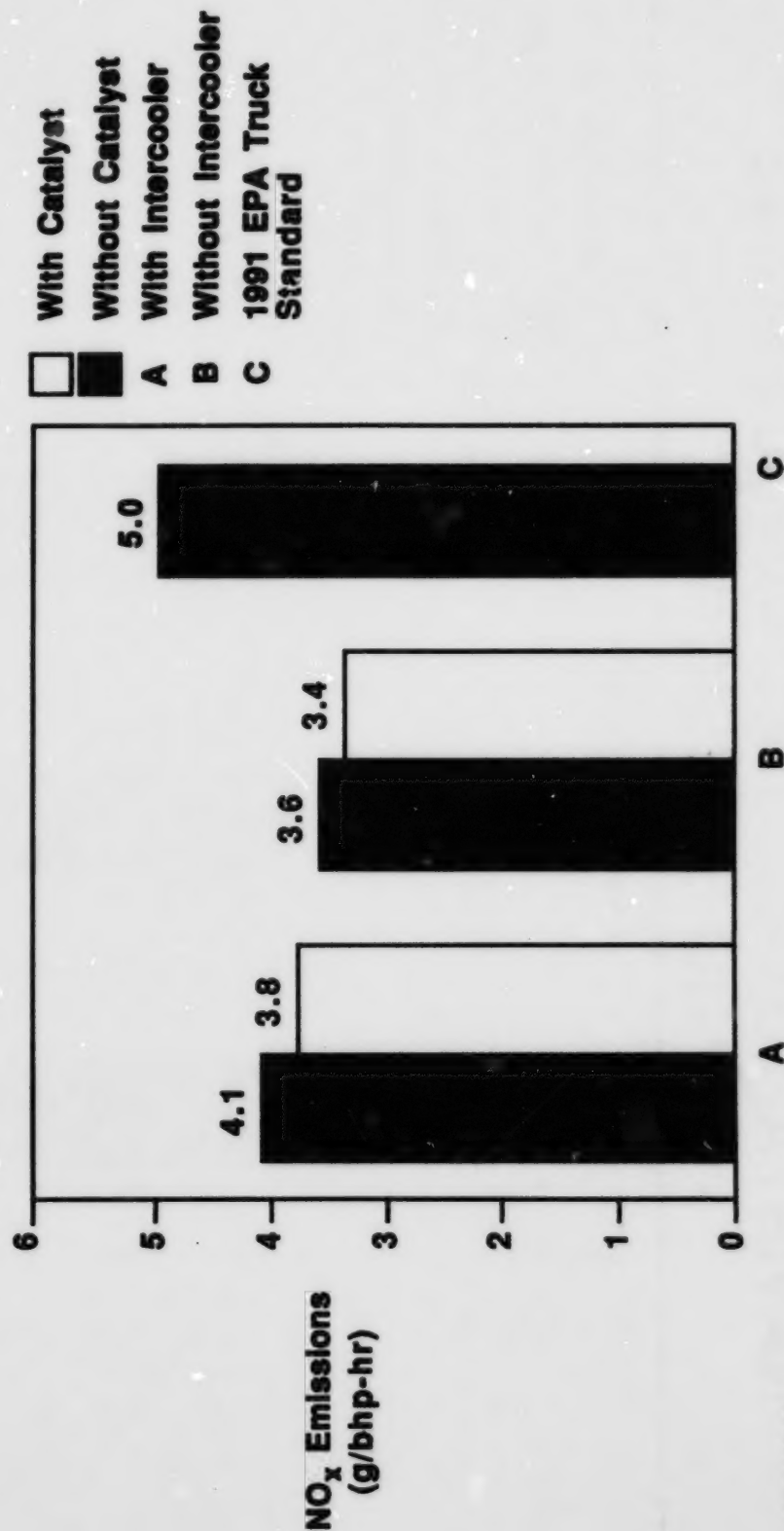
NAVISTAR DT 466 METHANOL ENGINE

- Engine development performed by Navistar and FEV
- Glow-plug assisted ignition using steel-shielded ceramic element glow plugs. Shield acts to regulate air-fuel mixture near hot element for better control of combustion and lower emissions
- Engine is turbocharged and available with intercooler; this application initially will not employ intercooler, but will include exhaust catalyst

NAVISTAR DT-466 METHANOL ENGINE HC EMISSIONS

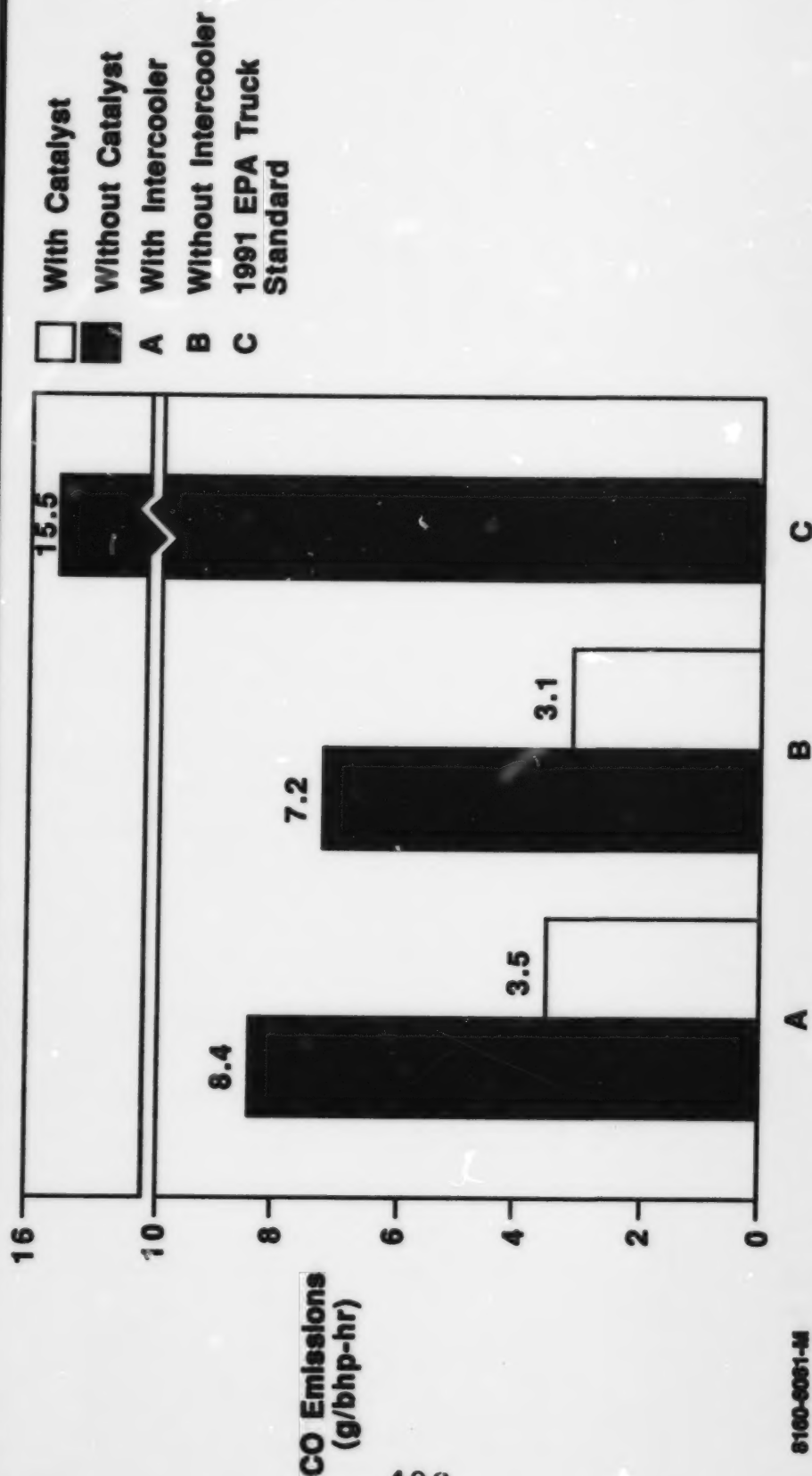


NAVISTAR DT-466 METHANOL ENGINE NO_x EMISSIONS

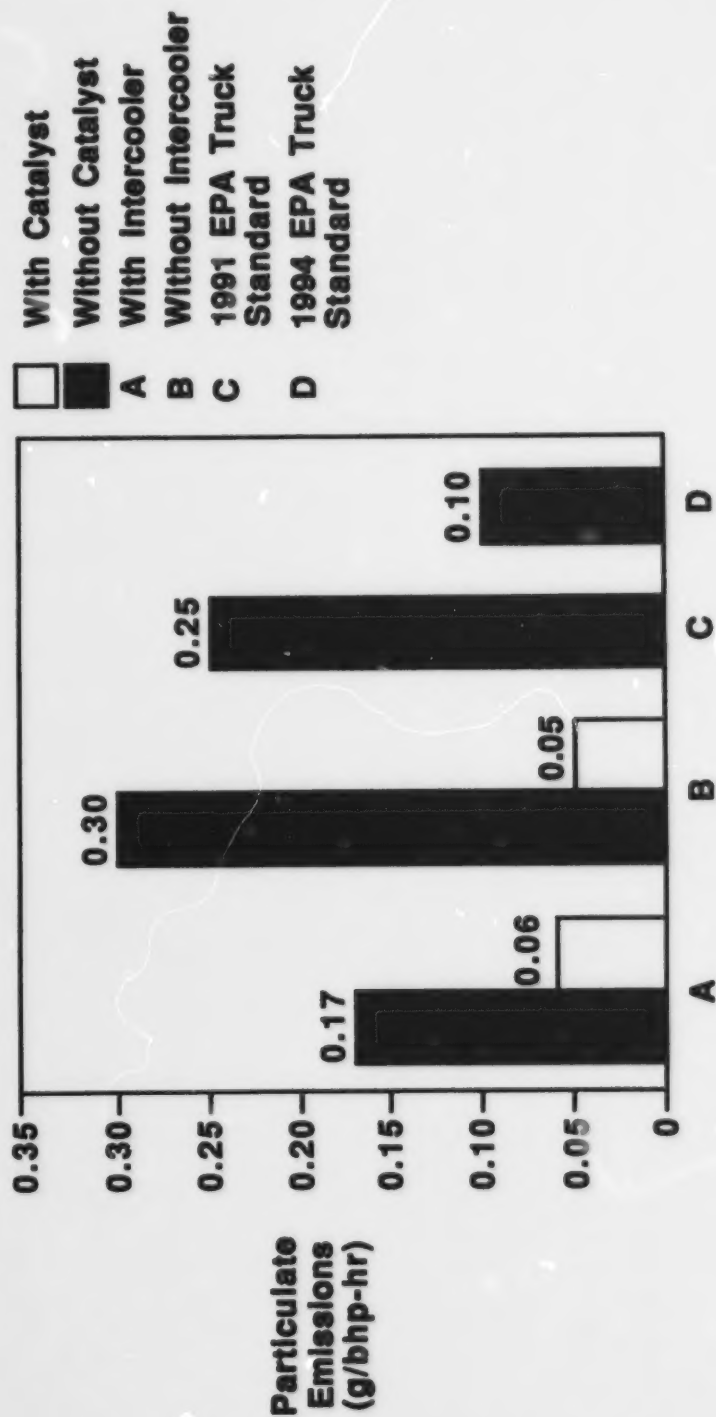


NO_x Emissions
(g/bhp-hr)

NAVISTAR DT-466 METHANOL ENGINE CO EMISSIONS



NAVISTAR DT-466 METHANOL ENGINE PARTICULATE EMISSIONS



CITY OF SOUTH LAKE TAHOE

- Navistar DT-466 methanol engine to be delivered to truck assembly plant for installation July 1990
- Truck modifications for methanol operation to be performed at Navistar International Truck Processing Center adjacent to assembly plant in Springfield, Ohio
 - Fuel tanks and lines
 - Exhaust catalyst
 - Glow-plug controller and wiring harnesses
- Truck will enter service September 1990
- M100 fueling facility construction scheduled to begin late July 1990

SUMMARY

- Three trucks have begun field demonstration to date, with six more scheduled to enter service within 30 days
- Fueling facilities installed or upgraded at three sites; two more currently in design/construction stage
- CNG site options currently being defined—will lead to addition of at least one or two CNG trucks in 1990
- Preliminary emissions results very encouraging
- Too early to comment on vehicle performance

ONTARIO NATURAL GAS TRANSIT BUS PROGRAM

**Joint Presentation
by
Ontario Transit Systems and
Ministry of Transportation
to
The 1990 Windsor Workshop
on Alternative Fuels**

**Dr. Toros Topaloglu
Head, Automotive Energy Section**



**Ministry
of
Transportation**

**Transportation
Technology and
Energy Branch**

Program Participants

- **Bus manufacturer**
 - **Ontario Bus Industries**
- **Engine supplier**
 - **Cummins Engine Company**
- **Fuel Suppliers**
 - **Consumers Gas, Union Gas**
- **Demonstration sites**
 - **TTC, Hamilton, Mississauga**
- **Research and development**
 - **ORTECH, Canadian Gas Association**
- **Governments**
 - **Federal, Ontario**

Natural Gas Bus Program Objectives

- **To assist transit systems in improving the efficiency and environmental acceptability of bus services**
- **To foster the development and supply of natural gas buses by original equipment manufacturers**
- **To provide energy diversity**

Bus Characteristics

- **Engine power** : 220 - 240 hp
- **Performance** : better than standard bus
using 170 hp 6v-71
- **Fuel capacity** : 14000 ft³
- **Range** : 650 km
- **Availability** : starting late '90

Compressor Station Design

- **Specification**

compressors	: 4
size	: 550 cfm
total capacity	: 2200 cfm
avg. fill time	: 4 min. to 2/3 full

Scope of Natural Gas Bus Program

- **Provide Toronto Transit and Mississauga Transit with three concept NG buses**
- **Ensure safety, efficiency and environmental acceptability of NG buses**
- **Provide Toronto Transit, Hamilton Street Railway and Mississauga Transit with 50 production NG buses**
 - **TTC 25**
 - **HSR 15**
 - **MT 10**
- **Establish NG fuelling stations**
- **Implement garage improvements**

Technical Considerations

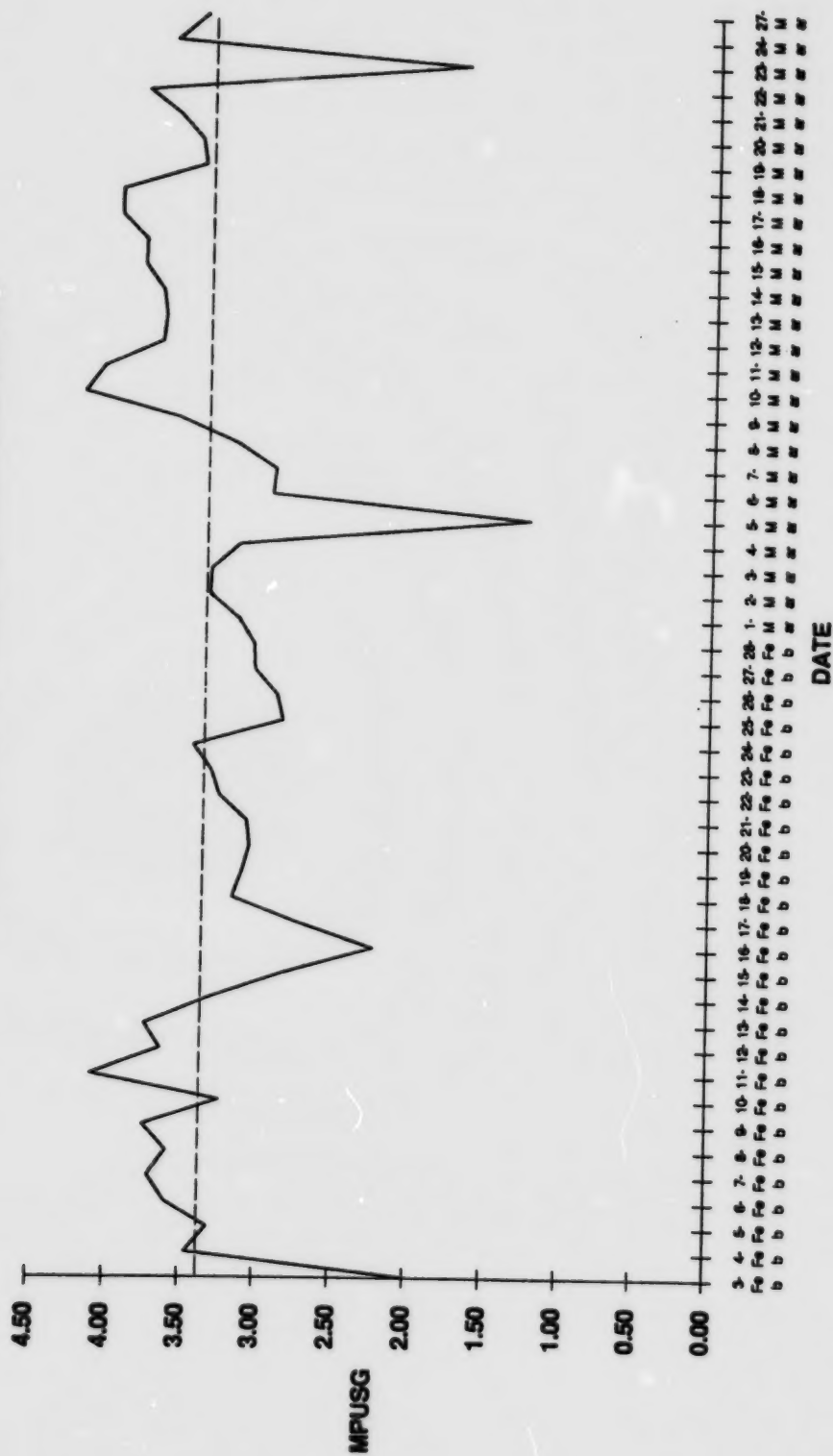
- **Continuous and rapid filling of buses with CNG requires a much larger fuelling station than current practice**
- **Present filling systems do not allow for gas heating effect in receiving cylinders → underfilling with respect to design capacity (~15% in 5-minute fill)**
- **Operation of current pressure limiting devices unsatisfactory: flow restriction, poor reliability**
- **Over-designing not acceptable → need optimum size of lines, couplings, buffer tanks and compressors**

Status of the Program

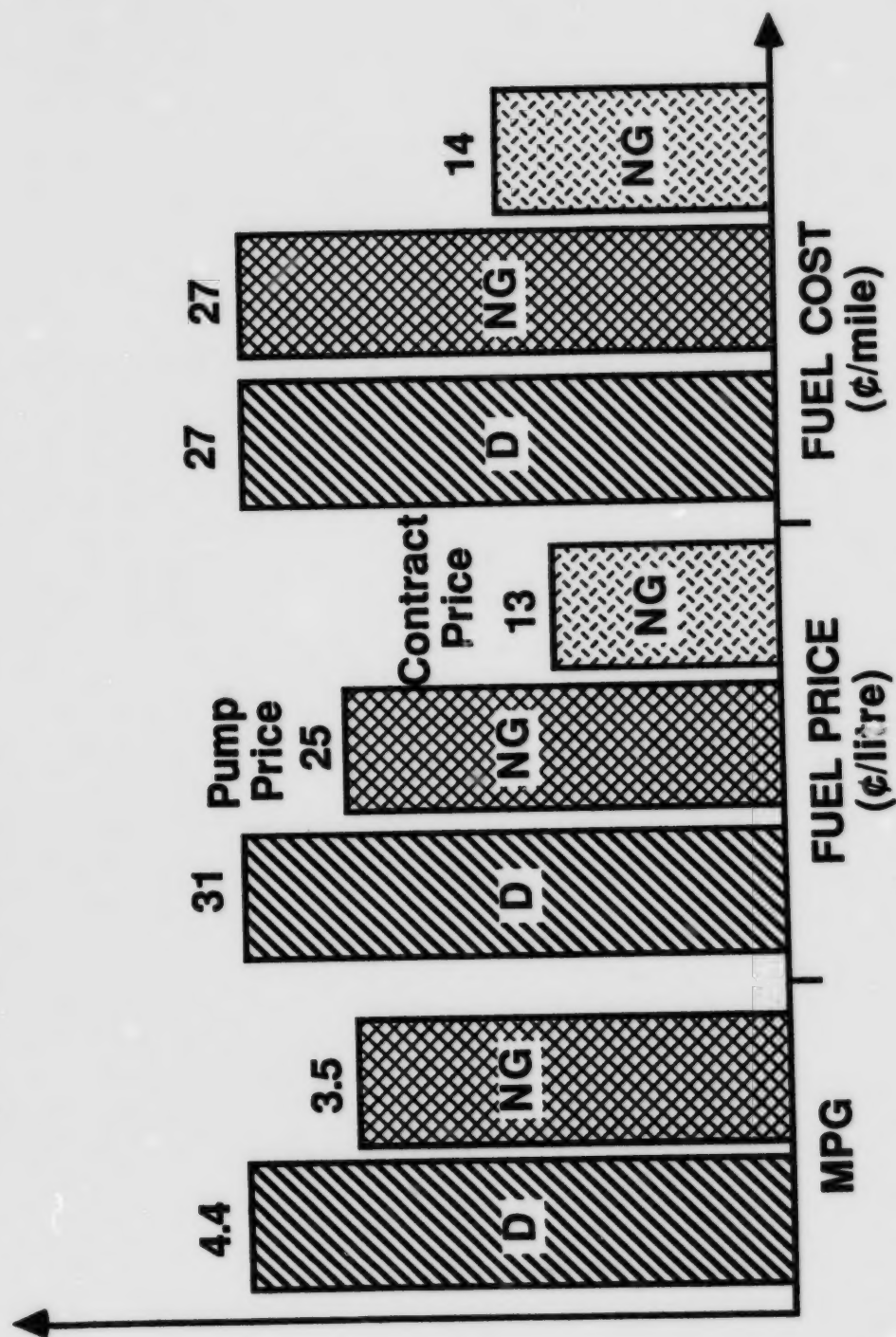
BUS

- **Three concept buses have been delivered**
- **Buses and engines have undergone initial assessment and refinements**
- **Data monitoring, analysis and reporting systems have been installed and are operational**
- **Prototype 102" bus is complete**

TTC NGV BUS #9360 FUEL CONSUMPTION



Comparison of Typical Diesel Bus with Natural Gas Bus (Ontario Data in US Units)



Status of the Program

Engine

- **Preliminary exhaust emission and durability tests completed on L-10**
- **Preproduction (Phase II) engine delivered**
- **Production engines will meet 1991 standard**

Status of the Program

Fuelling Station

- **Contract has been awarded**
- **Completion date Feb. '91**

TTC CNG Bus Fuelling Station Report

- **MTO operational study of typical bus refuelling and servicing operations → performance specifications**
- **Six proposals were received, and a design/build contract was awarded in the first week of February 1990**
- **Contract value: \$2.4 million (U.S.)**
- **Completion date: February 1991**
- **Status: at 60% design stage**

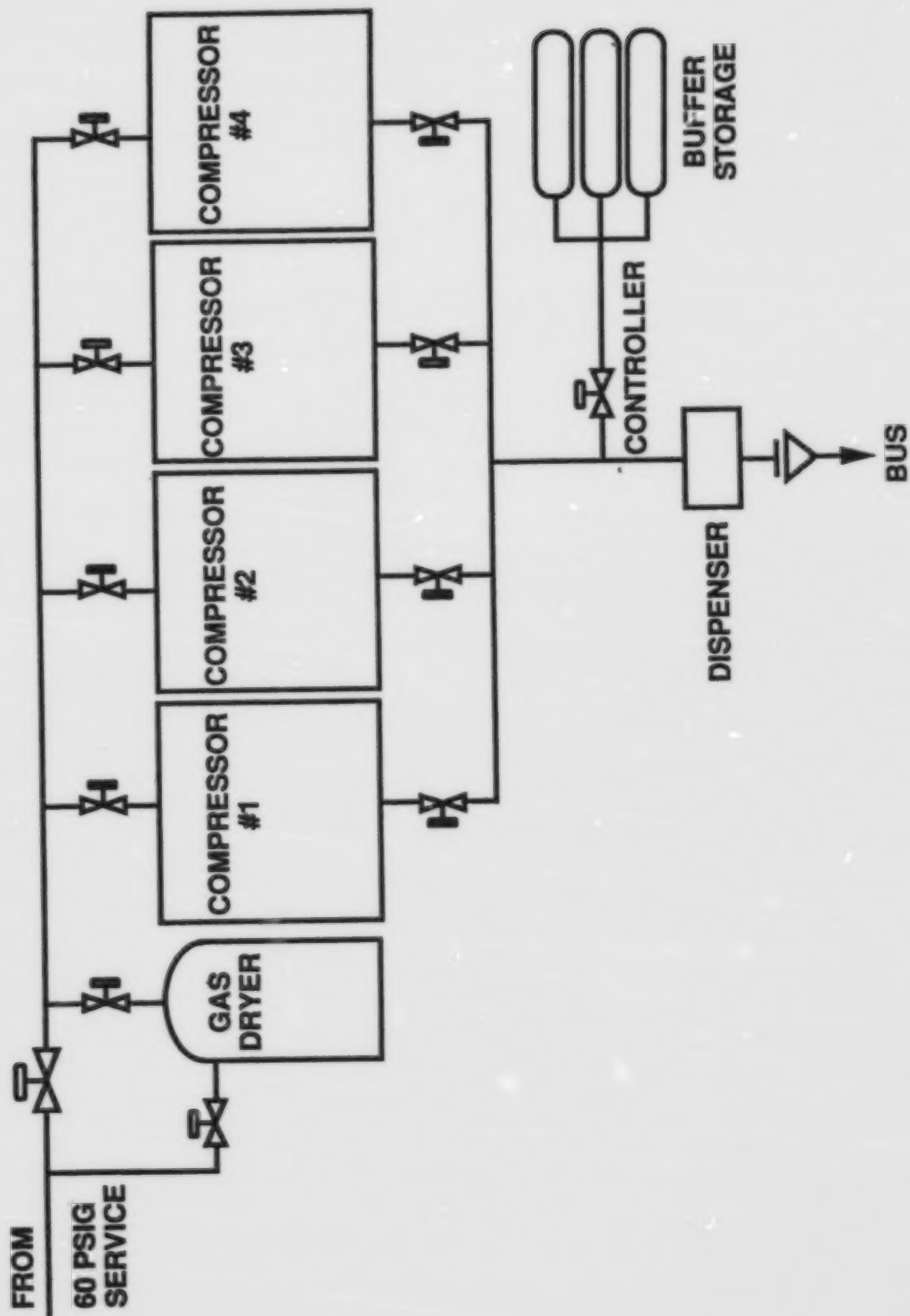
Operational Study Results

- **Average diesel fuel quantity delivered:
31 U.S. gal/bus**
- **Maximum diesel fuel quantity delivered:
70 U.S. gal/bus**
- **Maximum fuel delivery rate: 19 U.S. gal/min**
- **Average refuelling time: 117 seconds/bus**
- **Average total service time: 211 seconds/bus**

Performance Criteria

- **Service up to 125 CNG buses continuously**
- **Deliver 8800 SCF (175 kg) of CNG within 3 min and 45 sec of connect time and 4 min service time**
- **Modular design with adequate redundancy (maximum compressor rating of approx. 500 SCFM at 60 psig suction)**
- **Safe and reliable unattended operation**
- **Minimize cycling**
- **Equalize compressor utilization**
- **Temperature compensation**
- **Prevent over pressurization**
- **Maintain - 40°C dew point in CNG**
- **Maximum sound pressure of 65 dBA at 1 m from machine envelope**
- **Minimum maintenance and space, maximum efficiency and flexibility**

Fuelling Station Schematic



Status of the Program

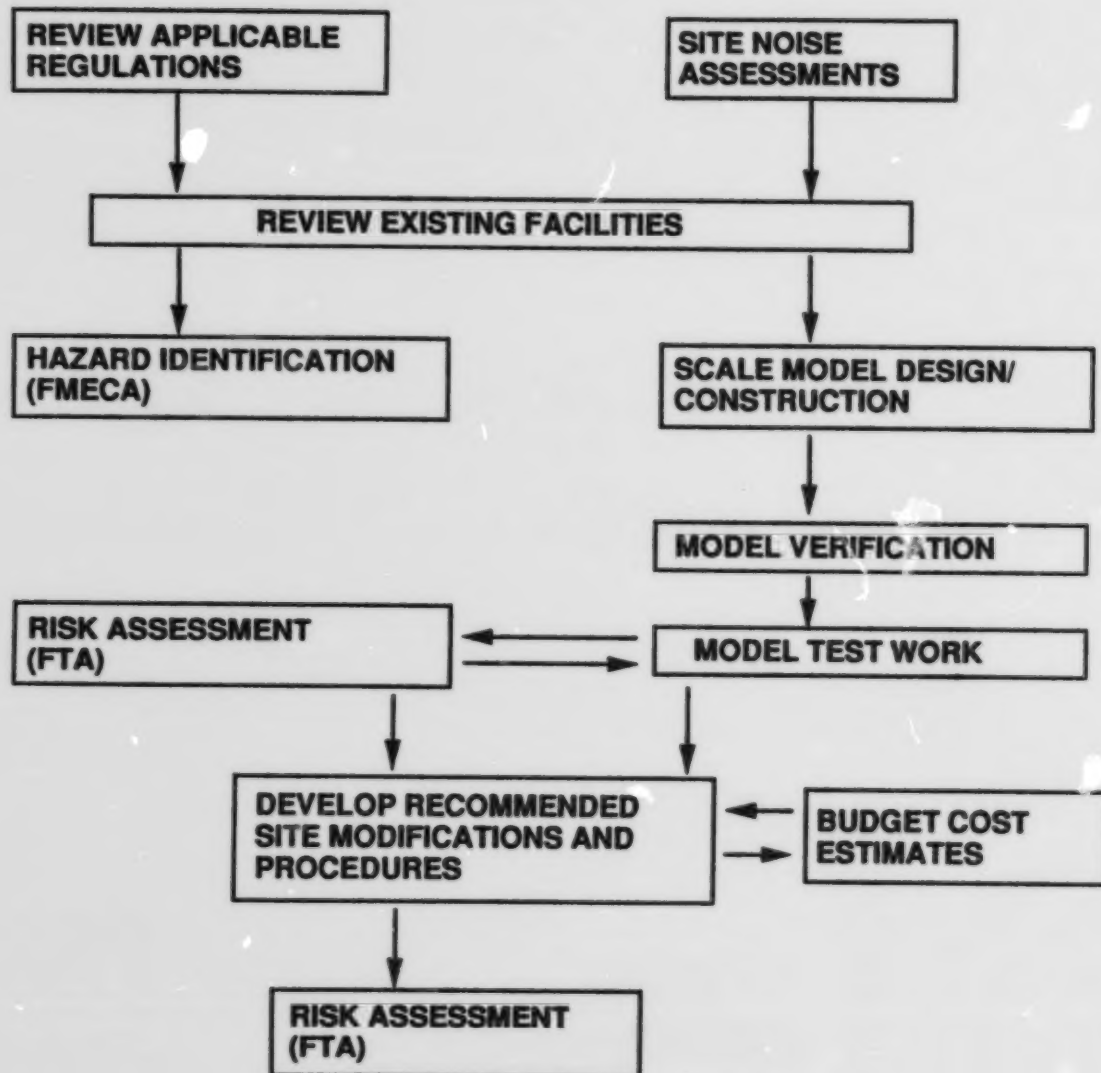
Site Assessment

- **Site assessment of TTC, HSR and MT garages is in progress**
- **A scale model of the garage and bus has been built to assess impact of leaks**

Scope of Project

- **Review of existing bus garages and operations (TTC Wilson garage, HSR Mountain garage and MT Central Parkway garage), applicable codes, accident records and NGV bus design**
- **Hazard identification**
- **Noise impact study**
- **Physical modelling and testing of each garage with respect to consequences of indoor NGV releases under a spectrum of conditions**
- **Risk assessment**
- **Development of recommended site modifications and procedures**
- **Cost estimation**

Project Methodology



Characteristics of Existing Bus Garages

- **Relatively low ventilation rates
(0.52 FPS ~ 1.02 FPS cross drafts)**
- **Open flame unit heaters**
- **Non-hazardous electrical classification**
- **Open and closed roof truss structures**
- **Carbon monoxide detection and ventilation
control**
- **Superior fire extinguishing systems**

Risk of Incident = Frequency of Hazard x Magnitude of Hazard



Fault Tree Analysis

Failure Rate Data

- Bus fuel system components
- Human error
- Accidents

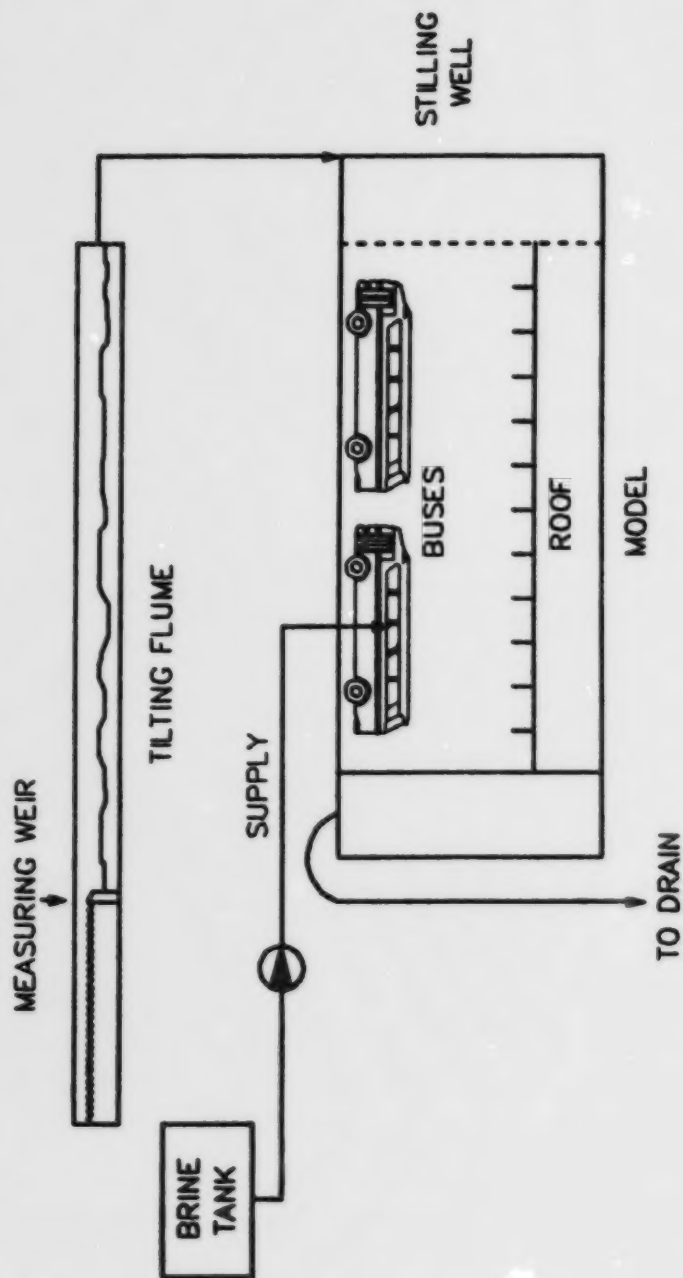


Consequence Analysis

Model Test Results

- Leak rate and location
- Building geometry
- Ventilation rate
- Ignition sources
- Safety precautions

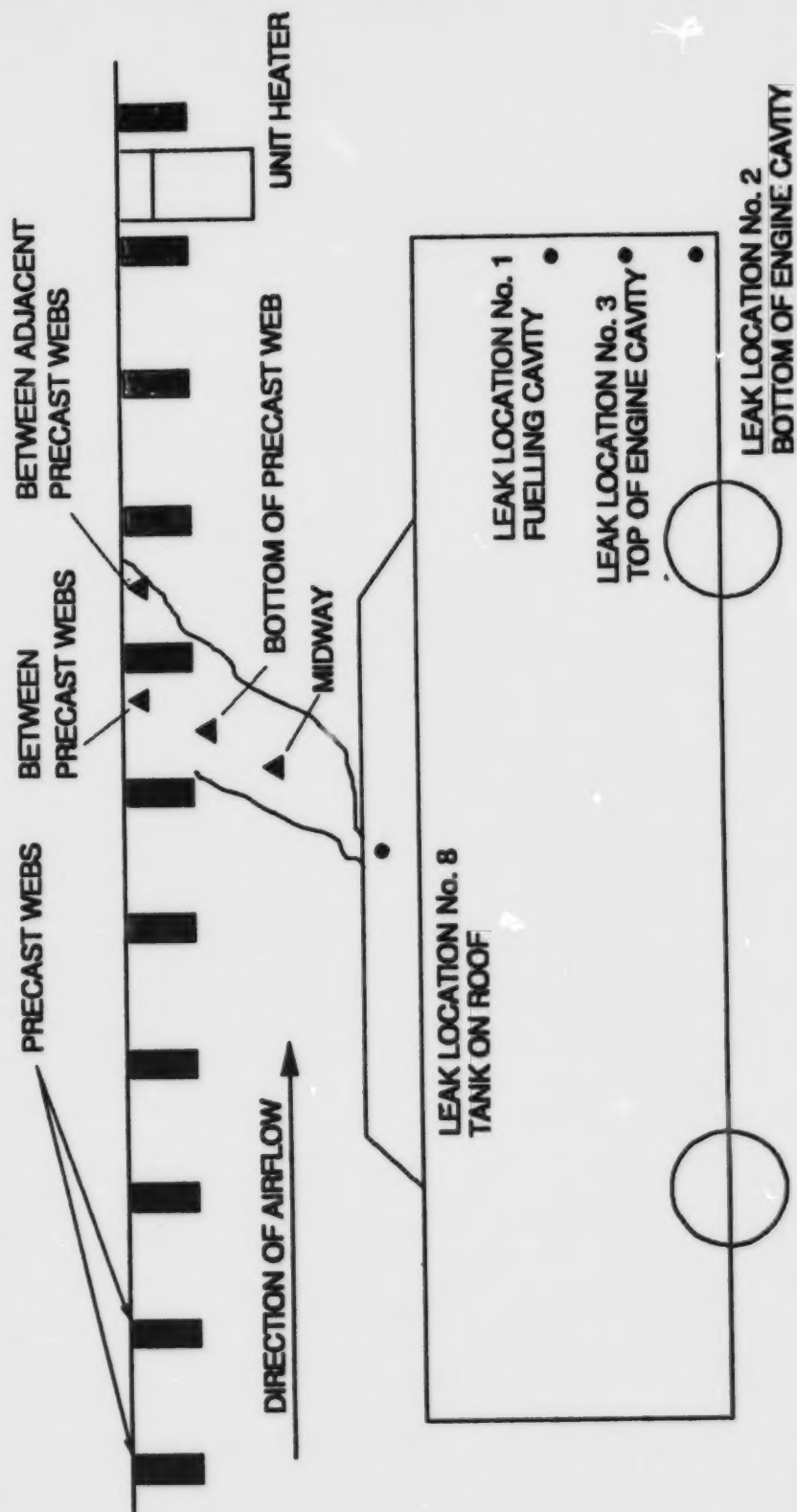
MODEL CONSTRUCTION



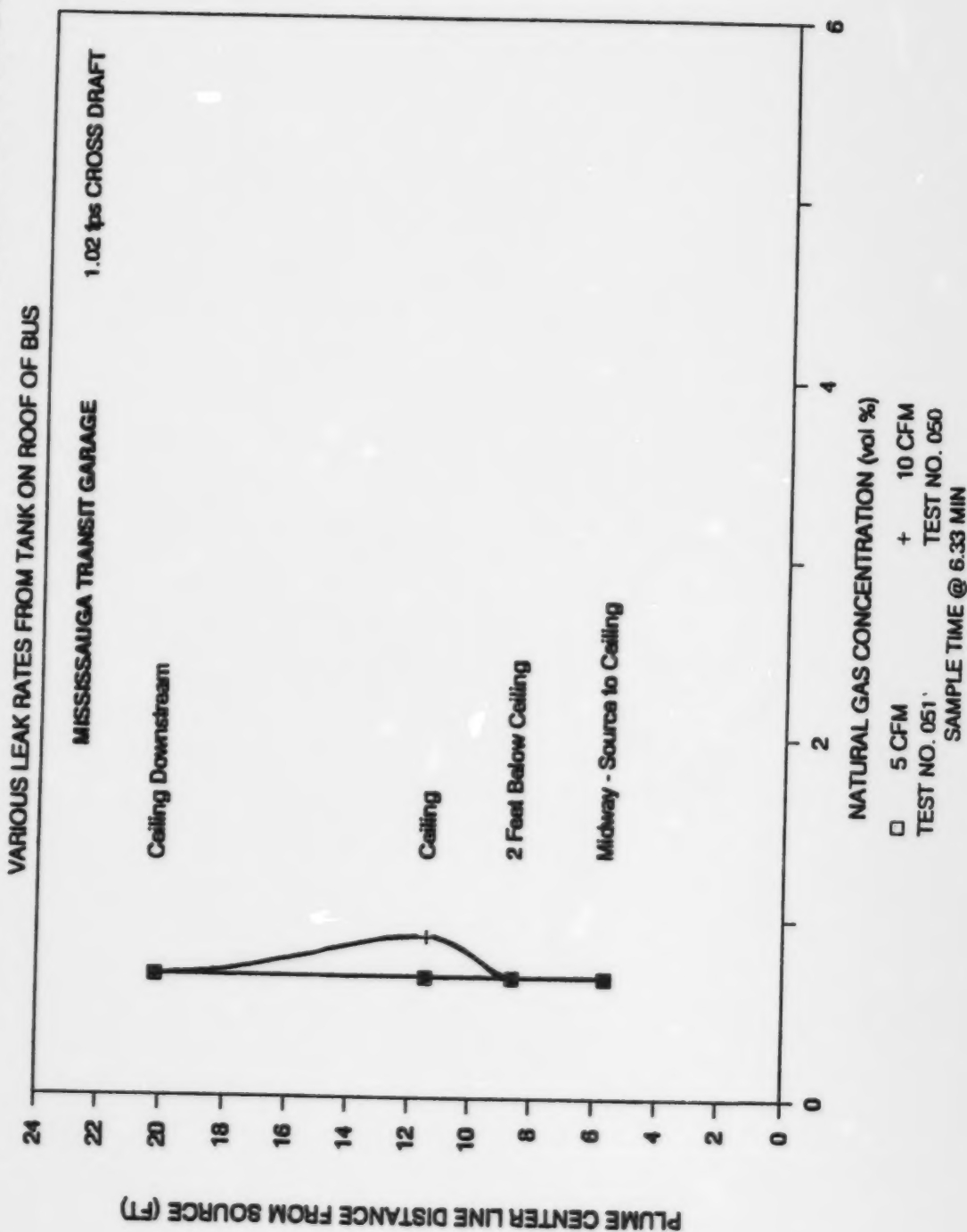
Variables Tested in Model Study

- **Natural gas leak location on the bus**
- **Natural gas leakage rates**
- **Building ventilation schemes**
- **Building ventilation flow rates**
- **Building geometry**

SKETCH OF TESTED LEAK LOCATIONS TTC - WILSON GARAGE

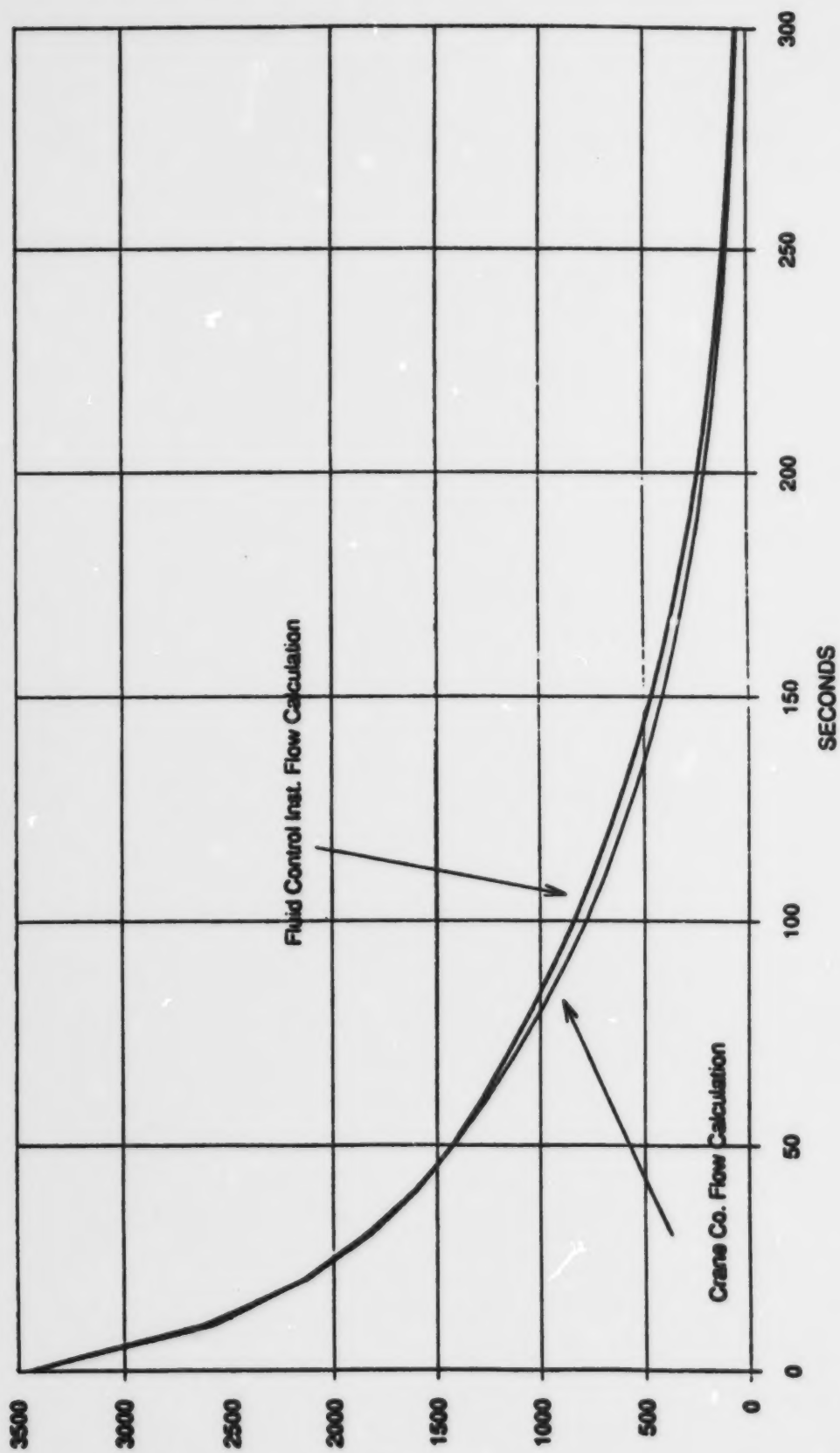


NG CONCENTRATION VS PLUME CENTER LINE DISTANCE

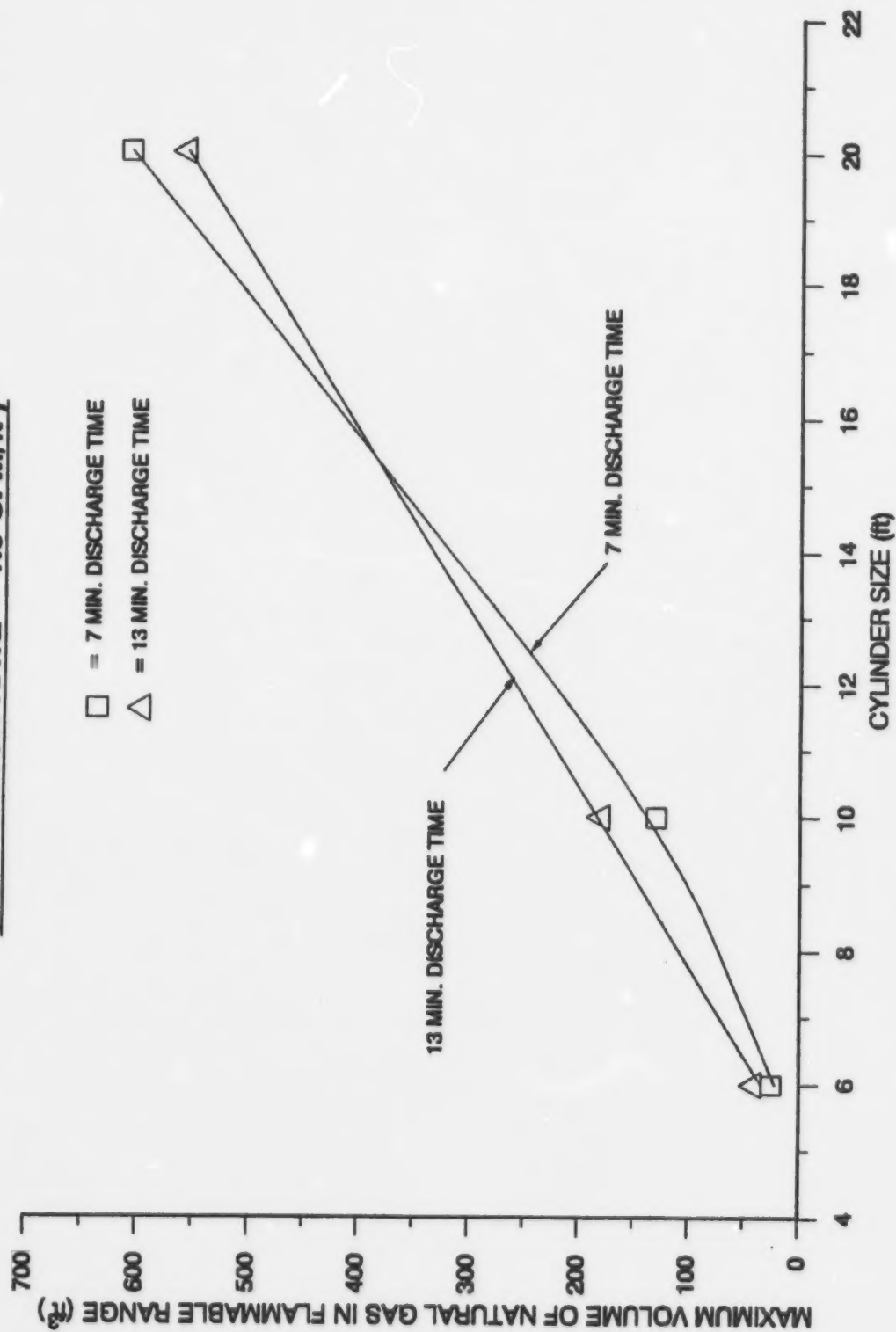


DISCHARGE OF NATURAL GAS CYLINDER

407 L, 3000 psig. through valve ($C_v = 1.5$) and 1 Ft of 3/8th tube

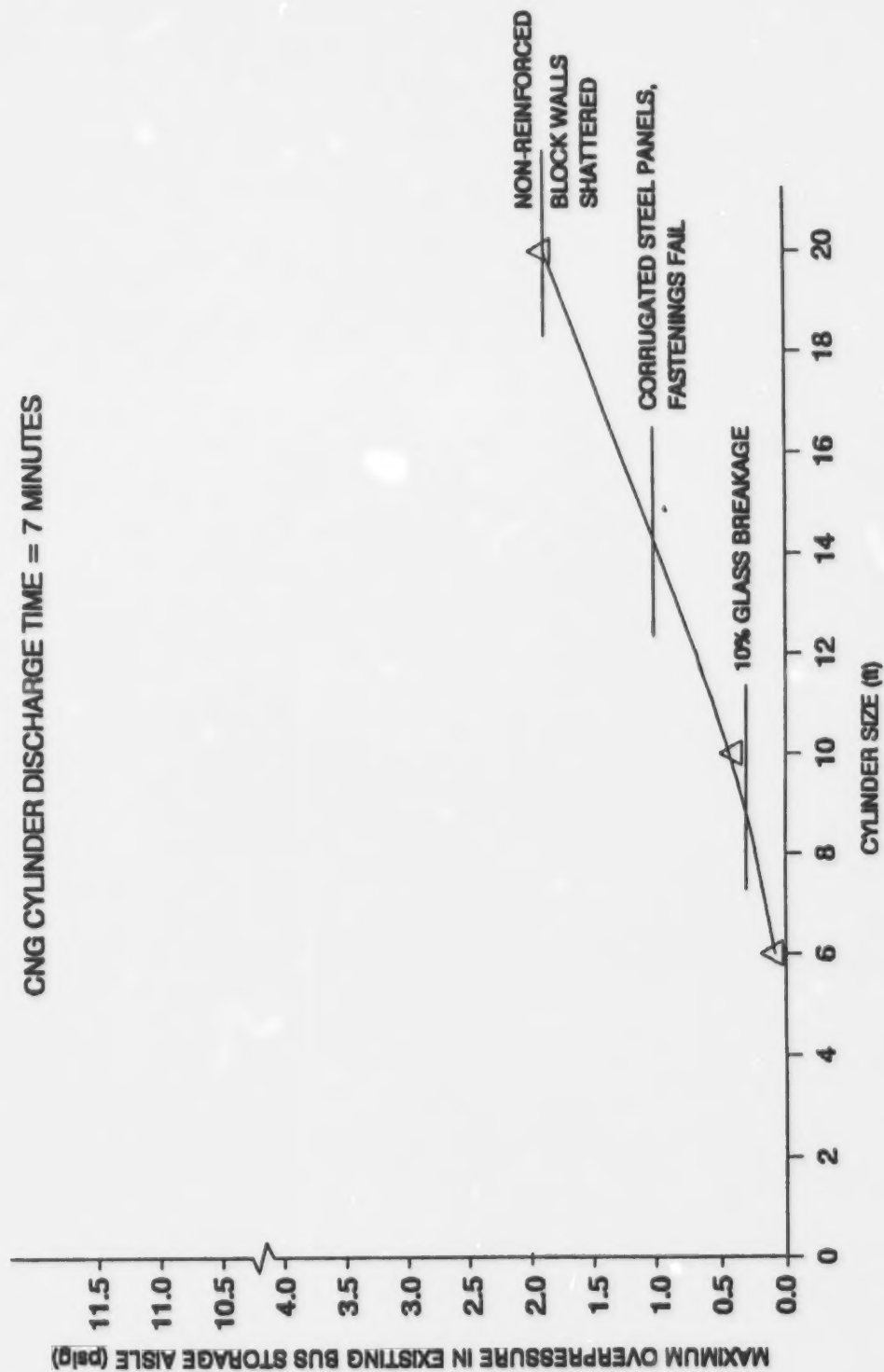


TTC WILSON GARAGE - MODIFIED VENTILATION
(VENTILATION RATE = 1.3 CFM/ft²)



TTC WILSON GARAGE - MODIFIED VENTILATION
(VENTILATION RATE = 1.3 cfm/ft²)

CNG CYLINDER DISCHARGE TIME = 7 MINUTES



Proposed Improvements

- **Higher ventilation rates**
- **New ventilation schemes
(updraft, mixing, two-level)**
- **Indirect heaters**
- **Spark-proof electrical systems**
- **Leak detection and warning systems**

Conclusions

- **Alternative fuels promise significant economic and environmental advantages**
- **The Toronto, Hamilton, and Mississauga experience is demonstrating the feasibility of operating transit buses on alternative fuels**
- **The Ontario NG bus program is progressing towards a full scale demonstration in the second half of 1990**

Ontario Bus Industries Inc.

1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 12, 1990

READINESS FOR MEETING 1991 TRANSIT BUS EMISSION STANDARDS

ONTARIO BUS INDUSTRIES (OBI) AND OUR U.S. SUBSIDIARY IN UPSTATE NEW YORK, BUS INDUSTRIES OF AMERICA (BIA) ARE MAJOR MANUFACTURER OF TRANSIT BUSES IN NORTH AMERICA, UNDER THE NAME OF ORION.

OUR COMPANY HAS FOR FOUR YEARS BEEN ACTIVELY ENGAGED IN THE CONVERSION TO NATURAL GAS AND LATER THE BUILDING OF COMPRESSED NATURAL GAS BUSES.

THIS HAS CUMULATED IN OUR PARTICIPATION IN A COMPREHENSIVE PROGRAM WHICH WILL BE REVIEWED TOMORROW AFTERNOON WHERE IT IS PLANNED TO DELIVER 50 CNG BUSES IN TORONTO, MISSISSAUGA AND HAMILTON.

TURNING NOW TO THE SPECIFIC QUESTION - READINESS FOR MEETING 1991 EMISSION STANDARDS. THIS CALLS FOR TWO QUESTIONS.

1. WHAT ARE THE 1991 STANDARDS? THIS IS A USA PROBLEM. IN CANADA, THE 1988 STANDARDS ARE BEING RETAINED FOR A WHILE.
2. WHAT DO WE MEAN BY BEING READY.

PAGE 2.

TAKING THE SECOND QUESTION FIRST, THE VERY MINIMUM FOR PRODUCTION, WOULD BE TO HAVE DEMONSTRATED 50,000 KILOMETERS OF TROUBLE FREE FLEET OPERATION IN DAY TO DAY SERVICE AND THIS WOULD TAKE AT LEAST 9 MONTHS.

ANY SELF RESPECTING TRANSIT SERVICE MANAGER WHO IS USED TO 350,000 MILE ENGINES AND EQUIVALENT TRANSMISSIONS, WILL TELL YOU THAT THAT IS NOT ENOUGH - AND PLEASE REMEMBER IT TAKES 10 TO 15 MONTHS TO BUY BUSES WHEN YOU KNOW WHAT TO BUY.

SO, RESPONDING TO THE FIRST QUESTION - "WHAT ARE THE 1991 STANDARDS", YOU CAN TAKE THE NARROW VIEW THAT IT IS THE .1 PARTICULATE HEAVY DUTY DIESEL STANDARD.

THE ANSWER TO THAT IS SIMPLE. WE ARE NOT READY. NO ONE CAN OFFER A SUITABLE ENGINE IN THE FORESEEABLE FUTURE.

LATE IN 1991, WE MAY WELL HAVE TRAPS AVAILABLE AND REMEMBER THESE TRAPS WILL HAVE TO BE CERTIFIED WITH THE ENGINE.

TODAY AS A BUS BUILDER, WE HAVE NOT YET BEEN ABLE TO OBTAIN SUFFICIENT INFORMATION TO START ENGINEERING THESE CUMBERSOME AND EXPENSIVE COMPONENTS INTO OUR BUSES.

IF YOU CHANGE THE QUESTION TO "WHAT WILL BE READY TO OFFER IN 1991", THE PICTURE CHANGES SOMEWHAT BECAUSE YOU HAVE SEVERAL OPTIONS:

PAGE 3.

1. BECAUSE IT IS THE DATE OF MANUFACTURE OF THE ENGINE THAT COUNTS, YOU CAN INSTALL 1990 ENGINES IN 1991 BUSES. IN OTHER WORDS STOCKPILING.
2. THE CLEAN AIR ACT IN BOTH HOUSE AND SENATE WOULD DELAY THE .1 CERTIFICATION AT LEAST ONE YEAR. THIS MEANS THAT TRUCK CERTIFICATE ENGINES COULD BE USED. WHEN THE CONFERENCE REPORTS WE WILL KNOW BUT THE ACT WILL ONLY BE PASSED IN SEPTEMBER.
3. THERE IS A PROPOSAL TO ALLOW NON CONFORMANCE PENALTIES BUT IT IS ONLY A PROPOSAL. THERE IS A LOT OF OPPOSITION. IN ANY CASE, THE LOGIC OF ONE FEDERAL GOVERNMENT DEPARTMENT EPA HAVING ISSUED NEAR IMPOSSIBLE STANDARDS, FINING ANOTHER FOR NOT MEETING THEM IS A STRANGE SITUATION. THIS IS SO BECAUSE THE D.O.T. URBAN MASS TRANSIT ADMINISTRATION FUNDS 80% OF CAPITAL COSTS IN BUS PURCHASES.
4. THERE WILL BE ANOTHER PROPOSAL TO ALLOW "BANKING AND TRADING" OF THE IMPROVED EMISSIONS OF CURRENT ENGINES WHICH ARE SUBSTANTIALLY BELOW CURRENT STANDARDS. HERE AGAIN, THIS IS A PROPOSAL WHERE WE DO NOT KNOW IF AND WHEN IT WILL BE CONFIRMED.

PAGE 4.

5. LATE IN 1991, AS MENTIONED BEFORE WE WILL SEE TRAPS. IT DOES SEEM TO US A VERY SHORT TIME TO FINALIZE DEVELOPMENT, DEMONSTRATE, PRODUCE AND CERTIFY THESE UNITS.

DO NOT FORGET, HOWEVER, THAT THEY APPARENTLY HAVE A COST OF THE SAME ORDER OF MAGNITUDE AS THE ENGINE.

6. FINALLY, WE COME TO WHAT IS AFTER ALL THE THEME OF THIS WORKSHOP - ALTERNATIVE FUELS.

ALTHOUGH PROPANE IS A POSSIBILITY, AND IN THE LONGER TERM THERE MAY BE OTHERS, IN THE FORESEABLE FUTURE THE TWO MAJOR ALTERNATIVES ARE METHANOL AND CNG.

METHANOL HAS HAD MORE EXPOSURE TO FLEET DAY TO DAY OPERATIONS BUT WE BELIEVE IT FAIR TO SAY THAT IT IS ONLY TODAY THAT A TROUBLE FREE FLEET DEMONSTRATION COULD BE DEEMED TO BE STARTING. I THINK IT WOULD BE RASH TO SAY THAT WE CAN BE ASSURED TODAY THAT IT WILL BE IMMEDIATELY SUCCESSFUL.

THE SITUATION WITH CNG IS SIMILAR BUT NOT QUITE SO FAR ADVANCED. IF THE TORONTO PROGRAMME IS IMMEDIATELY SUCCESSFUL, IT COULD BE DEEMED TO

PAGE 5

HAVE STARTED IN THE LAST QUARTER OF THIS YEAR SO
IN BOTH CASES, TO SAY WE WILL BE READY IN 1991 IS
PUSHING THINGS TO SAY THE LEAST.

NOT TO MENTION, THE OTHER PROBLEMS IN CONNECTION WITH
ALTERNATIVE FUELS.

A MAJOR ONE IS INFRASTRUCTURE. WHO IS GOING TO
SPEND A LOT OF MONEY UNTIL IT HAS BEEN DEMONSTRATED THAT
LARGE FLEETS CAN BE SUCCESSFULLY AND ECONOMICALLY OPERATED.

ANOTHER IS REGULATIONS - CNG EMISSION STANDARDS HAVE NOT
BEEN ISSUED YET. THERE IS NO CNG FUEL TANK STANDARD OR
CERTIFICATION PROCEDURE IN PLACE. MANY OF THE OTHER
STANDARDS OR REGULATIONS ARE NOT CLEAR OR ARE OUT OF DATE.

FINALLY THE HIGH COST OF THESE ALTERNATIVE FUEL BUSES MAY BE
A HINDERANCE..

SO THERE IS A LOT OF WORK YET TO BE DONE.

FINALLY, WE WOULD LIKE TO ADD THAT IT IS DISTURBING TO SEE
THAT THERE IS NOT MORE EMPHASIS IN TWO AREAS WHICH COULD BE
VERY REWARDING IN REDUCING TRANSIT BUS EMISSION.

FIRST TO IMPROVE EMISSIONS OF VEHICLES ALREADY IN SERVICE
AND SECONDLY TO CONCENTRATE ON EMISSIONS PER MILE OR EVEN
PER PASSENGER MILE INSTEAD OF GRAMS PER BRAKE HP HAVE ON A
TRUCK TRANSIENT CYCLE.

PAGE 6.

**THIS HAS LED TO THE CURRENT SITUATION OF 27 HP BUSES WHEN A
HYBRID BUS COULD PROBABLY MANAGE WITH 125 HP.**

HI TECH APPROACH FOR NATURAL GAS BUSES IN SCANDINAVIA

by

Mats Ekelund

**President
Ecotraffic AB
Gamla Brogatan 29
111 20 Stockholm
SWEDEN**

Windsor Workshop, Toronto June 12 1990.

Mats Ekelund is the President of Ecotraffic, a Stockholm based consultant company operating in the field of alternative motorfuels. Ecotraffic operates a number of domestic and international motor fuel studies and surveys. Hardware projects are managed by Ecotraffic as well as Governmental and Industrial counselling.

Mats is Vice President of IANGV (International association for Natural Gas Vehicles) and an IGU-NGV Task Force member.

Currently, Mats holds a position as Program Manager and assistant to the Professor of Transport-Technology at Chalmers University of Technology in Gothenburg. His responsibility is alternative motor-fuels logistics.

ONE SUNNY DAY, LATE AT NIGHT
 TWO DEAD BOYS HAD A FIGHT
 BACK TO BACK THEY FACED EACH OTHER
 DREW THEIR SWORDS AND SHOT EACH OTHER

IF YOU DON'T BELIVE ME, YOU CAN ASK THE BLIND AND
 DEAF POLICEMAN ROUND THE CORNER, HE SAW IT ALL.

This might show how confusing the alternative motorfuels debate has been for a number of years. Over the last couple of years results of experiment have yeilded some insight for new directions.

Methane as a motorfuel is one of the alternatives. This presentation will Focus on one suitable approach.

DIFFERENT DEMANDS

Public demands on the emissions discharges from heavy duty vehicles are much higher in Scandinavia than the demands in any written legislation. As long as polutant levels are increasing or stable we expect this demand to grow stronger. European OEM:s have met and exeeded written and known future legislations already. It seems however that there yet is a long way to go before public demand is satisfied to meet requirements for metropolitan areas with current fuels, dramatic quality increase must take place. It is obvious that alternative fuels must be used instead of the current fossile fuels.

CO-NORDIC NATURAL GAS BUS PROJECT

In late 1986 the advisory Nordic Council of Ministers held to a seminar and opened discussion on how to reduce city-bus exhaust discharges. A prestudy was issued, indicating the possibility of reducing exhaust emissions significantly.

In 1988, Transit Authourities in the Nordic capital cities formed The Co-Nordic National Gas Bus Project.

Diesel-operated buses:

- are reliable
- are durable
- have well build up after-market services
- have well known operating expenses etc

If the industry would switch to an alternative -fuel it must be anticipated that a significant improvement can be made in one or more areas without decreasing any other current line of operation, so significant that current technology cannot be expected to meet the alternatives expected results.

Methane is a simple chemical composition. It is expected that with correct treatment, methane fueled vehicles can operate with a significant reduction of exhaust emissions. So significant that current available technologies cannot meet these results.

Project targets are defined in the US FTP cycle as(g/kWh):

CO	HC	NOx	Part	
US 1991 bus	20,7	1,7	6,3	0,13
Target	2	1	2	<0,1

These targets do not correspond to any written or future known standard, they relate more to needs and public demand. Please note that the targets were defined in 1988. If they can be met in this first engine developmentphase, further development can most likely meet even higher demands.

COST AND EXPENSES

There seems to be a major concern about purchase price and investment. There also seems to be a great concern for energy prices.

Over the life-time of a bus, drivers cost exceeds 50% Energy costs tend to be around 5% and financing of investment only a small percentage. A major concern would be engine and vehicle wear, out of service hours, workshop size, staff and equipment, etc.

Fuel cost and extra investment do not necessarily increase lifetime cycle cost, whereas the correct way of calculating overall operational costs should be based total "Life" Cycle Cost"

In the case of natural gas or even bio-based methane operations, such a cost might be less than or equal to today's diesel operation.

PROJECT EXECUTION

The five capitol transit authorities form the executive committee. They report to a group of 30 funding organizations. The execution of the project is made by a project manager, in this case Ecotraffic, with the help of staff with special skills. During the project the steering committee reports three times. Steering committee meetings are held about every third month.

Saab-Scania and Volvo are among the funders of the project. They also make an active contribution and take active the developments part in. Other funders are Transit Authorities, heavy duty vehicle users, governments, authorities and fuel suppliers.

The project cost for two years cover some USD 2 million.

Please note that natural gas utilities are not in a decision making position. Only Transit Authorities, I.E. users are the decision makers.

PROJECT DEMANDS

Emission targets have already been mentioned as (g/kWh) 2 (CO) - 1 (HC) - 2 C (NOx) - 0.1 (Part), measured in the FTP cycle. Additionally the 11 liter Scania, and the 10 liter Volvo engine must also meet the following criteria:

- 180 kW
- 1000 Nm torque
- max 750° C exhaust temperature
- good driveability

OPTIONAL TECHNOLOGIES

Generally there are two ways to reduce exhaust emissions from a methane operated engine. One option is stoikometric operations with a TWC, the other is lean-burn with an oxidizing catalyst. Volvo suggested lean burn tecnology and Scania TWC technology.

It was agreed that the transfer of new technology would be open between the two competetive OEM:s, whereas their different choises of technology was a "bingo" as well for the project as for the two OEM:s. They will consequently be able to chose the inbetween the two technologies if an introduction on the market-place will come in question.

LABORATORY WORK

Eight different laboratories were invited to suggest details on which way to go and how to do it. Their suggestion were as follows:

<u>TWC</u>		<u>Lean-burn</u>	
Ricardo	GB	SwRI	USA
TNO	NL	ORTECH	Can
AVL	A	United Turbine	S
VTT	SF	Marintek	N

Of these, Ricardo and SWRI were choisen. One of the reasons were their possibilities of measuring results according to the FTP cycle.

All laboratories, except perhaps for ORTECH, underestimated the need of control-system speed and accuracy. Temperature in access to details in technology limited other laboratories.

Ricardo

Fast burn during combustion can be acheived with Ricardos Nebula designed piston crown. Fifteen to eighteen degrees crank angel can be achieved instead of twenty to twenty-five with the "Mexican-hat" shaped piston. Nebula design allows BGR, at a 15 to 20% range without knocking.

EGR is inert and does not influence the stoichiometric properties. Therefore an engine with this equipment is as well a TWC as a lean-burn engine. A sophisticated control-system is required to handle all parameters at all conditions speed is crucial as all operations must be kept within very narrow limits.

SWRI

Prechamber ignition forms high NOx but gives an energetic spark, so energetic it can ignite an extremely lean mixture. The higher NOx from the PC is well compensated by lower NOx in the main chamber

SWRI's meaning is that this technology can very well be used in cylinders with a bore as small as Volvos 125 mm.

The energetic spark will allow mixture to be very lean ($\phi = 1,6-1,85$) without any dramatic increase of unburn HC. For HC reasons the choice of crankshaft time was also important.

Initially controlsystem design was expected to be less complicated than a TWC-system would be. Wider lambda area would put less demand on the system. It appears however that:

- Nox vs HC trade off
- Waste gating
- Divided fuel supply systems
- bring demands to equal levels.

RESULTS

Ricardo laboratory results are, at this time, expected to meet the demands as stated above.

At this time no definite indication related to results can be quoted from SWRI. NOx results (2g/kWh) can be met with a penalty on CO and HC which was undersired. Reliability in the fuel supply system must be increased.

Whether backpressure - EGR will improve results is yet to be determined.

VTT-laboratories in Helsinki Finland have converted a Finish-manufactured, 7,4 l inline 6 cylinder engine. Kemiras TWC was used during ECE R 49 test. Caterpillar 3306 with Englehart TWC has likewise been tested according to ECE R 49.

	CO	HC	NOx
Valmet	0,1	0,1	0,4
Caterpillar	0,41	0,12	0,51

Results like this are a joke, for two reasons:

- 1 Spark ignited engines can much less than dieselengines, compare transient and steady state results.
- 2 There is not a control-system accurate enough.

The valuable side of these results are two:

- 1 They indicate future possible exhaust-emission levels.
- 2 They give us an indication of where control system technology might take us from here.

CLIMATE GASES

Methane is known to be a greenhouse gas. Discharges unburned natural gas can be compared with pipeline leakage. CO₂ makes a 4 times greater impact, according to current findings than unit of methane.

Greenhouse effect from discharges of unburned methan are really only a fraction compared with the effect from discharges of CO₂. They should not be neglected but there are two other major facts to consider:

- 1 By increasing thermal efficiency, CO₂ emissions will be reduced as they are directly related to energy consumption.
- 2 Natural gas is not the only methan source available. Sewageplants and wastetreatment-plants produce a number of TWH annually.

Stockholm has a sewageplant covering some 5-600 000 people. Methane from this plant can more than supply all of Stockholm 2100 metropolitan buses.

Bio-produced methane let into the atmosphere contributes to the green-house effect just like any other green-house gas. Bio-methane, used in an engine however has no negative contribution as this methane is used instead of discharged.

CO₂ from combustion of bio-methane will get into the atmosphere as fast anyway, whereas CO₂ is there regardless of any operation or use.

The city of Linköping will operate six buses from early 1991 on sewage methane. We expect the operation to be as smooth as any other natural gas operation.

A comparatively new method, using an advanced filtering process, will be used to clean the raw gas. The final gas will have a 97% methane content with a penalty of 7% of the energy.

We expect to see a lot of domestic and international attention on this project.

CYLINDERS

Substantial weight reduction and safety increase can be achieved by using a composite fibre cylinder. Northern located ABB-Plast manufactures a carbon fibre cylinder, now in use in Malmö Transportation. Buses can carry 600 km (400 m) storage on the roof and in the chassi still meeting strict weight requirements

Failure during:

- abuse
- static fatigue
- cyclic fatigue
- fire

is in all known cases substantially benefited with a composite cylinder.

Even though there is a high price to this product, there will be a market for this product everywhere where there is a high safety concern.

PROJECT CONTINUATION

After finalizing engine development a small scale project of 5 to 10 buses will operate somewhere in Scandinavia. OEM:s will be expected to have a greater involvement than before.

If the project proves succesful one whole bus-fleet of 75 - 125 buses will operate on methane. Transit authourities all over Scandinavia are standing in line to be selected for this next stage.

Technology should at that time be such that a decicsion can be made about a possible commercial introduction of methane as a city-bus fuel.

A number of parallel studies will indicate quality and standard requirements for:

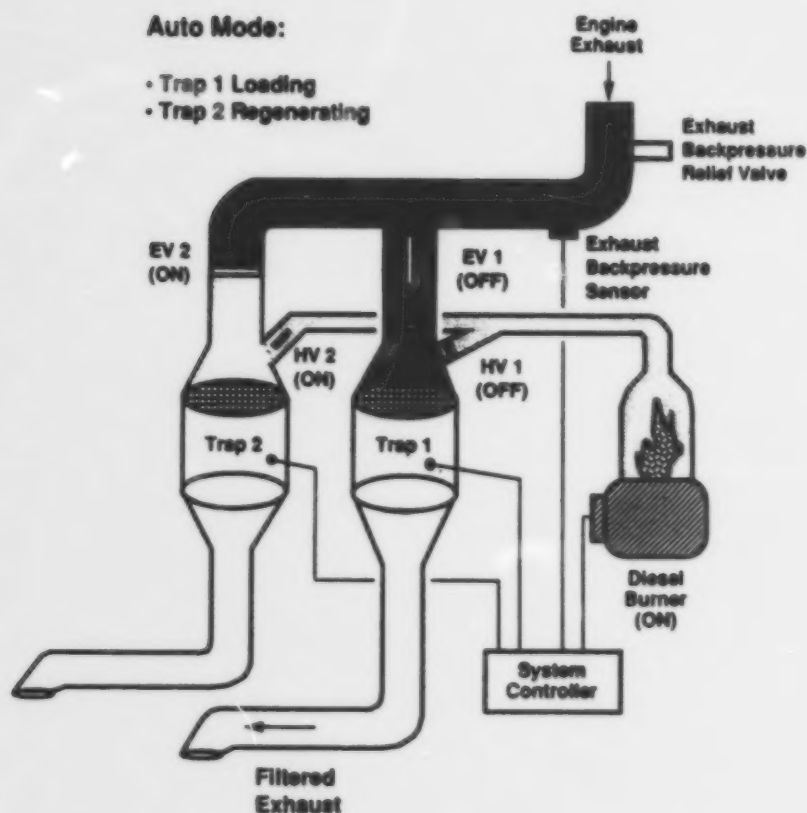
- compressors
- nozzels
- pressure
- refueling
- etc

A great concern for safety will also be given priority.

CONCLUSSIONS

- 1 Methane is expected to prove itself a significant value as a HD metropolitan fuel.
- 2 Methane gas is expected to prove a viable alternative.

NEW YORK CITY TRANSIT AUTHORITY PRESENTATION TO 1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS



TORONTO, ONTARIO
JUNE 11-14, 1990

**TRAP OXIDIZER PROGRAM
NEW YORK CITY TRANSIT AUTHORITY**

**1990 WINDSOR WORKSHOP ON
ALTERNATIVE FUELS**

TECHNICAL SUPPORT

TECH REPORT ON FIELD EVALUATION

The New York City Transit Authority:

- Operates a fleet of 3580 buses
- On 229 routes with
- 5169 runs in all five boroughs.
- Each year these buses travel over 100 million miles
- At an average speed of 6.7 MPEH.
- The operating budget for the calendar year is 860 million dollars.

Air quality in New York City is a major problem. The NYCTA is committed to reducing its contribution to the problem, so we can remain the clean air alternative!

Surface Transit's primary contribution to the air quality problem is diesel particulate matter.

During the last ten years the New York City Department of Environmental Protection has quantified our contribution to the problem. On average a typical bus traveling 180 miles a day emits about 1 lb. of particulates. If you extrapolate this number using the operating statistics just presented, you will have a good idea of the magnitude of the problem.

One way of dealing with this bus emission problem is through the use of exhaust after treatment.

Specifically in this case we refer to a trap oxidizer system.

Bus 1698 was returned to the NYCTA from Ortech with the prototype trap oxidizer system installed in March of 1989.

After a shakedown, inspection and system break-in period, the bus entered revenue service on the M-15 route in Manhattan.

The M-15 route was chosen for the Trap Demonstration Program because of its difficult duty cycle, that is:

- Low ground speed
- High passenger density
- High frequency of stops per mile

This route also operates in areas of Manhattan where a significant PM-10 problem exists.

Since the bus entered the field evaluation portion of the demonstration program, a daily performance record for bus 1698 and 10 control buses has been collected and evaluated. In addition, any unusual conditions noted by the operator while the bus was in service or detected on the service line during routine maintenance inspection and service were verified and addressed.

From April 3, 1989 - February 4, 1990, bus 1698 accumulated:

- 14,600 miles
- 2337 engine hours
- With an average ground speed of 6 MPEH
- Had a fuel economy of 2.12 MPG
- Oil consumption was 700 MPQ
- The Trap System accumulated 4575 regeneration cycles.

The control fleet of 10 similarly configured RTS 04 buses also equipped with mechanically injected 6V-92TA engines with a TA V730 had an average accumulation of:

- 19,500 miles per bus
- An average ground speed of 8 MPEH
- A fuel economy of 2.5 MPG
- Oil consumption averaged 550 MPQ

The accumulated mileage differential of 23% between the trap equipped bus and the control fleet is significant and requires explanation. The differential can be attributed to the following factors:

- The trap equipped bus undergoes routine testing at the New York City Department of Environmental Protection emission test cell on a regular basis.
- The trap equipped bus is routinely removed from service for trap system demonstrations.
- Since only one trap equipped bus existed for most of the evaluation period, system optimization, troubleshooting and enhancements required additional out-of-service time.

FUEL ECONOMY DIFFERENTIAL

The fuel economy differentials between the trap equipped bus and the control fleet was 14.6%. This penalty exceeds the 3 to 6% fuel penalty which had been anticipated prior to the field evaluation. The reasons for the excessive differential were:

- **DEMONSTRATION TIME** - a significant amount of idle time has been accumulated on the trap bus, especially during demonstration programs. Interest in the trap program has been high, but this interest has impacted revenue service time and has increased the fuel consumption penalty.
- **PRESENT DIESEL BURNER CONFIGURATION** - The diesel burner used on bus 1698 is a modified off-the-shelf burner identical to those used as a coolant heaters or truck operators cab.

The burner for the trap system is located in the bus engine compartment under the air cleaner housing and over the transmission. The burner is required to deliver the heat necessary to start regeneration in a ceramic trap through about 10 feet away and around a 90° corner. Obviously, this will require more energy than a system where the burner is located adjacent to or integrated into the trap housing itself; however this is a prototype system designed to demonstrate the potential of a trap oxidizer system in a transit bus application, not a production system.

- **REGENERATION INTERVAL** - One of the program goals was to maximize the number of regeneration cycles to obtain some reliability data on the traps themselves.

The current loading time for the trap system is 30 mins. per unit. This requires that the burner be on 18.3 min. per hour.

A typical duty bus will produce about 2.5 grams/mile of particulates. Previous trap optimum regeneration will occur with the trap about 50% loaded or at 20 grams of particulates. This represents about 1 hr. and 30 mins of loading time even in our duty cycle. Therefore, we could reduce the frequency of our regeneration cycles and related fuel consumption significantly, bringing us very close to the calculated values.

PROBLEMS - The trap oxidizer system on bus 1698 has exhibited some problems. The problems are in two major classes:

- System Problems
- Reliability Issues

THE SYSTEM RELATED PROBLEMS ENCOUNTERED WERE:

- Burner Photo Optical Flame Detection Sensor
- Elbow Temperature Sensor
- Heating Pipe Insulation
- Component Weatherproofing
- Manner Of Treating Overloaded Trap Monolith

BURNER PHOTO OPTICAL FLAME DETECTION SENSOR

The purpose of this sensor is to have a safety device to ensure that fuel flow through the burner nozzle only occurs when a flame is present. Beginning last June, when high ambient temperatures were seen, the trap diagnostic system recorded burner fault conditions. These conditions could be caused by insufficient burner voltage or a defect in the photo electric flame sensor. Separation of the burner head from the combustion chamber indicated that the optical sensor was clouded with soot.

Possible causes of this problem were:

- Poor fuel quality
- Poor seating of trap/exhaust diverter valves
- Non-optimized combustion ratios for the application environment

Problem analysis determined that high ambient temperatures and an installation modification made to the combustion chamber created poor fuel combustion, causing high levels of soot on the optical sensor.

In order to minimize the impact on mileage accumulation from this problem, a program of weekly cleaning of the photo eye during periods of high temperature was incorporated until the burner system could be optimized. The time to perform this function is approximately 7 mins. per/week. It would be noted that burner optimization on a more recent trap demonstration bus equipped has been accomplished and the impact towards reducing the occurrence of photo eye sooting is being monitored.

ELBOW TEMPERATURE SENSOR

On August 30, bus 1698 recorded a system over temperature failure mode. This fault indication was designed to occur if external heat tube temperature at the outer radius of the 90° elbow exceeded 135°C. It was assumed that this portion of the heat tube would undergo extreme thermal stress and could be a significant reliability issue. Analysis of the system determined that the thermal sensor in use had failed and no real system over temperature had occurred.

ELBOW TEMPERATURE SENSOR (cont'd)

The sensor was replaced with one which is typically used in vehicle applications and no further over temperature events occurred on bus 1698, or the 2nd generation trap equipped buses which are equipped with identical sensors.

HEATING PIPE INSULATION- The insulating blanket used to cover the heat tubes has not met the requirements of the system. The insulation blanket has been damaged by normal engine compartment cleaning procedure and has required replacement.

COMPONENT WEATHERPROOFING- Fault indications were recorded in the system at significant the thermocouple over temperature situations. Analysis of the problem found that water and dirt had entered the thermocouple junction box, oxidizing components. A new box was made and no further problems have occurred.

MANNER OF TREATING OVERLOADED TRAP MONOLITH

During the demonstration period one trap failure occurred. The trap failure occurred during a manual regeneration.

A careful analysis of this failure was performed. Our findings were:

- Bus 1698 was checked on Monday August 7, 1989, prior to entering normal revenue service and was found in E-stop. When an E-stop condition exists on the trap system, an audible signal from a horn should occur at intervals to alert the bus operator to a trap system problem.
- A review of depot records found that bus 1698 had been reported for an unknown buzzer by a bus operator on Saturday August 5, 1989. Depot maintenance personnel, not familiar with the trap system, disconnected the time delay horn relay and returned the bus to service. The bus accumulated an additional 139 miles with the trap system disabled.

On Monday, when personnel familiar with the trap system found the bus in E-stop, they proceeded with normal troubleshooting procedures which included manual regeneration. During this regeneration, thermal runaway occurred.

MANNER OF TREATING OVERLOADED TRAP MONOLITH (Cont'd)

The thermal runaway occurred because the trap system had accumulated an estimated particulate load of 174 grams during the 139 miles and 23 engine hours. In order to prevent recurrence of this condition, the following changes were made:

- Circuit logic was reversed and the relay was epoxied in place to insure safe failures.
- Control program has been modified to indicate elapsed time that trap system is in fault (CNT-37).
- The estimated loading was derived from New York City Department Environmental Protection data for the engine in bus 1698 prior to trap installation. In addition, failure analysis of trap performed by Corning reached a similar conclusion.
- Depot personnel were retrained on alarm and signal circuit for trap system.
- Additional decals were installed in electrical Spparatus box.
- Troubleshooting procedures have been modified to insure manual regenerations are not conducted on traps with more than eight hours of accumulation time without special precautions.

THE RELIABILITY ISSUES ENCOUNTERED WERE:

- Maintenance Intervals
- Life Of System Components
- Impact Of Related Bus Subsystems

MAINTENANCE INTERVALS

The particulate trap oxidizer system has required no change to established preventive maintenance intervals. Currently all buses receive a quality assurance inspection daily and receive detailed mechanical inspections every 3,000 miles.

We have seen no indication use of a that particulate Trap Oxidizer System will require this to change.

LIFE OF SYSTEM COMPONENTS AND IMPACT OF RELATED BUS SUBSYSTEMS

The demonstration bus has not experienced component failures which could be attributed to the trap system. The only engine unit failure which occurred was a water pump seal on bus 1698. This is a common failure.

Spectrochemical oil analysis is a normal part of our preventive maintenance inspection. The oil conditions found on the trap bus were similar to non-trap equipped overhauled engines, that is high silicon readings for the first 6000-9000 miles.

Exhaust back pressure was checked weekly to insure no changes were occurring due to increasing efficiency of the trap system.

RECOMMENDATIONS:

The data accumulated from bus 1698, as well as the three additional trap oxidizer equipped buses, have led to the following recommendation:

- Expansion of demonstration programs using various regeneration methods as well as alternative substrates is needed to clearly define all the reliability and durability issues which may occur.
- The diesel burner must be optimized to improve reliability and reduce its impact on fuel consumption.
- More data is needed to determine the full impact that particulate trap oxidizer systems will have on transit operations and clearly define the maintenance and durability issue.

The New York City Transit Authority has purchased 400 buses which will be equipped with a particulate trap oxidizer system designed to meet the 1991 emission requirements. This large scale demonstration will provide the information necessary to meet 150,000/290,000 mile maintenance/durability requirement of the federal emission rules.

CONCLUSIONS:

What conclusions has this demonstration led to:

- Bus 1698 to date: 60 weeks of revenue service
(June 6, 1990) 21,287 miles
3,371 engine hours
5,541 trap regeneration cycles
2.15 miles per gallon average

CONCLUSIONS: (Cont'd)

- Particulate emissions reduced by over 80 percent
- Carbon monoxide reduced by 50 percent
- Small reduction in oxides of nitrogen
- No deterioration in trapping efficiency to date
- Particulate trap oxidizer system is technology that can be retrofitted in a standard transit bus.
- With the inclusion of the recommended improvements particulate trap oxidizer systems are a viable, cost effective way of reducing emissions from urban transit buses
- With further development, a particulate trap oxidizer system will meet the 1991 US Environmental Protection Agency emission standards for urban buses

NEW YORK CITY TRANSIT AUTHORITY

**TRAP OXIDIZER PROGRAM
PROJECT DATABASE**

TECHNICAL SERVICES

LEGEND

- 3 test were completed at the New York City DEP emissions lab in Brooklyn, New York
- Two test where conducted using non-catalyzed traps (Jan 22/ 23, 1990 and March 26/27, 1990)
- one test was completed using a catalyzed trap (March 28, 1990)
- % reductions numbers where calculated based on the following formula;
$$(\text{baseline} - \text{test}) / \text{baseline} \cdot 100$$
- Trap #1- Drivers side of the bus
- Trap #2- Door side of the bus

NY-BUS CYCLE

DONALDSON SYSTEM				NYCTA BUS #4517			
	BASELINE AVG	NON CATALYZED TEST #1	% REDUCTION	NON CATALYZED TEST #2	% REDUCTION	CATALYZED TRAP TEST #1	% REDUCTION
THC	8.897	8.583	3.53%	8.044	9.58%	6.824	25.54%
CO	9.091	8.799	3.22%	8.355	5.90%	4.453	51.02%
NOx	73.541	73.637	-0.13%	65.732	10.62%	63.991	12.99%
PART	1.645	0.606	63.16%	2.074	-25.08%	1.454	11.03%

3-M SYSTEM SEPTA BUS			
	BASELINE AVG	SYSTEM AVG	% REDUCTION
THC	6.9855	7.2245	-3.42%
CO	9.5905	10.925	-13.91%
NOx	60.1545	62.574	-4.02%
PART	1.1595	0.4515	61.06%

BASELINE EMISSION TEST RESULTS
NOVEMBER 27 and 28, 1989
GRAMS/MILE

BASELINE #1 VALUES

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.054	3.846	8.826	4.013	3.930
CO	3.33	3.991	8.797	4.112	4.052
NOx	27.936	33.018	73.306	32.444	32.731
PART	0.768	0.885	1.617	0.922	0.904

BASELINE #2 VALUES

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.197	3.961	8.967	4.03	3.996
CO	3.648	4.184	9.385	4.298	4.241
NOx	27.395	32.291	73.779	32.254	32.273
PART	0.847	0.935	1.673	0.875	0.905

AVERAGE OF BOTH BASELINE #1 AND #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.126	3.904	8.897	4.022	3.963
CO	3.489	4.088	9.091	4.205	4.146
NOx	27.666	32.655	73.541	32.349	32.502
PART	0.808	0.910	1.645	0.899	0.904

NON-CATALYZED EMISSION TEST RESULTS

JANUARY 22 and 23, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.309	3.829	8.294	3.84	3.835
CO	3.452	3.851	8.858	4.183	4.017
NOx	28.4274	30.873	73.601	31.858	31.366
PART	0.844	0.514	0.665	0.578	0.546

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.088	3.943	8.871	4.03	3.987
CO	3.399	4.141	8.739	4.126	4.134
NOx	28.583	32.334	73.672	32.239	32.287
PART	0.415	0.428	0.547	0.458	0.443

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.199	3.886	8.583	3.935	3.911
CO	3.426	3.996	8.799	4.155	4.075
NOx	28.505	31.604	73.637	32.049	31.826
PART	0.630	0.471	0.606	0.518	0.495

MARCH 26 and 27, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.035	3.556	8.242	3.614	3.585
CO	3.366	3.833	8.327	3.742	3.788
NOx	26.298	29.206	66.595	29.086	29.146
PART	0.873	0.741	2.414	0.643	0.692

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.853	3.562	7.846	3.576	3.569
CO	3.544	4.073	8.783	4.117	4.095
NOx	26.197	29.257	64.868	28.542	28.900
PART	0.877	0.757	1.734	0.705	0.731

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.944	3.559	8.044	3.595	3.577
CO	3.455	3.953	8.555	3.930	3.941
NOx	26.248	29.232	65.732	28.814	29.023
PART	0.875	0.749	2.074	0.674	0.712

CATALYZED EMISSION TEST RESULTS

MARCH 28, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.121	2.78	6.809	2.717	2.749
CO	1.789	2.3	4.663	2.048	2.174
NOx	25.567	28.405	64.385	27.973	28.189
PART	0.648	0.659	1.701	0.681	0.670

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.023	2.944	6.439	2.745	2.845
CO	1.417	2.393	4.242	2.3	2.347
NOx	25.804	28.825	63.996	28.179	28.502
PART	0.525	0.546	1.226	0.566	0.556

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.072	2.862	6.624	2.731	2.797
CO	1.603	2.347	4.453	2.174	2.280
NOx	25.686	28.615	63.991	28.076	28.346
PART	0.587	0.603	1.464	0.624	0.613

7 REDUCTIONS FROM BASELINE
(USING A NON-CATALYZED TRAP)
JANUARY 22 and 23, 1990

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	-6.01%	1.94%	6.83%	4.52%	2.42%
CO	1.11%	5.93%	2.65%	0.54%	0.85%
NOx	-2.73%	5.40%	-0.08%	1.51%	4.17%
PART	-4.75%	44.75%	60.61%	34.76%	39.57%

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	1.20%	-1.01%	0.29%	-0.21%	0.23%
CO	2.58%	-1.31%	3.87%	1.88%	2.53%
NOx	-3.32%	0.98%	-0.18%	0.34%	-0.04%
PART	48.61%	52.97%	66.75%	49.03%	51.05%

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	-2.34%	0.45%	3.53%	2.15%	1.30%
CO	1.82%	2.24%	3.22%	1.20%	1.72%
NOx	-3.04%	3.22%	-0.13%	0.93%	2.07%
PART	22.04%	48.24%	63.16%	42.35%	45.30%

REDUCTIONS FROM BASELINE
(USING A CATALYZED TRAP)
MARCH 28, 1990

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	35.27%	24.58%	27.62%	31.74%	28.16%
CO	59.39%	41.46%	53.34%	45.30%	43.38%
NOx	6.73%	11.73%	13.52%	12.89%	12.31%
PART	34.98%	40.00%	25.47%	37.01%	38.50%

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	32.14%	28.78%	23.46%	32.44%	30.61%
CO	48.72%	43.73%	48.71%	51.30%	47.51%
NOx	7.59%	13.01%	12.45%	13.53%	13.27%
PART	19.75%	27.58%	-3.40%	24.21%	25.89%

AVERAGE OF BOTH TRAPS

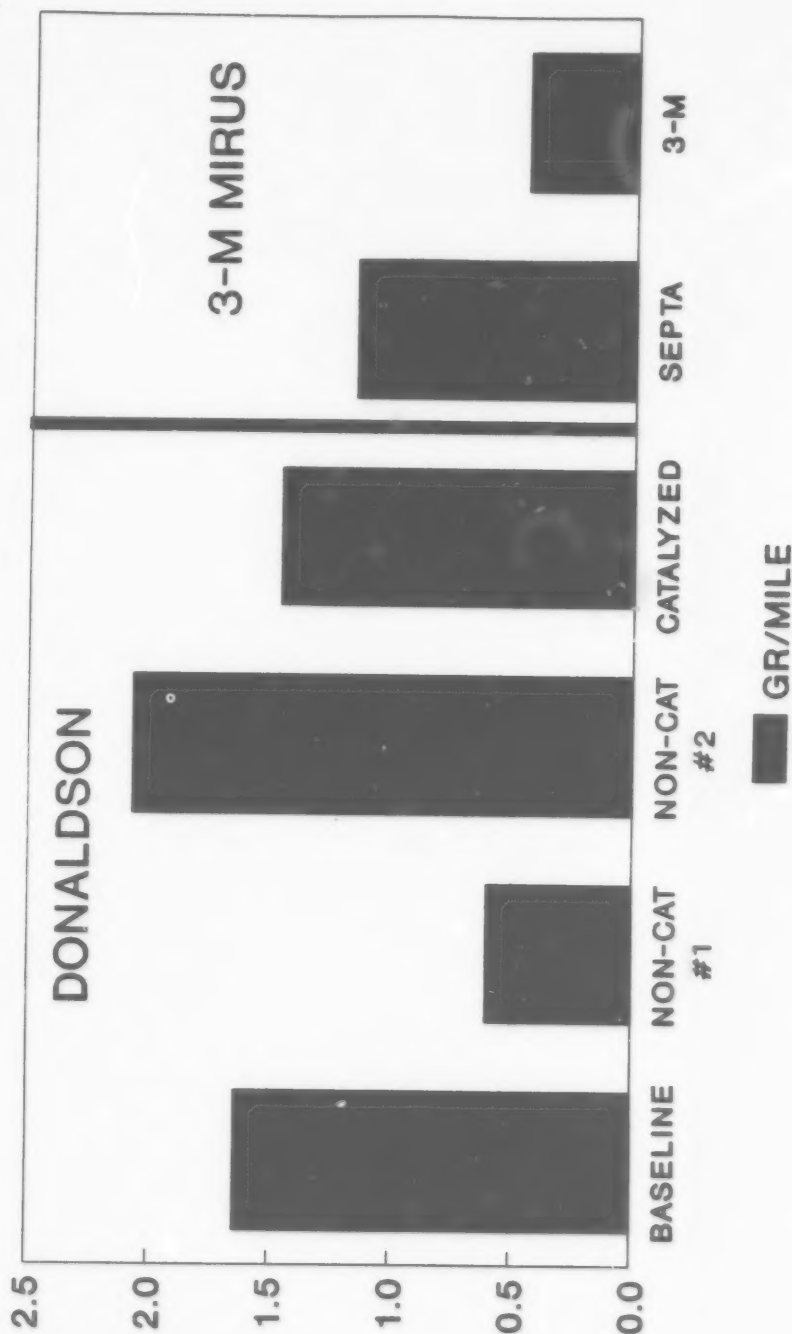
	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	33.71%	26.68%	25.54%	32.09%	29.39%
CO	54.06%	42.59%	51.02%	48.30%	45.45%
NOx	7.16%	12.37%	12.99%	13.21%	12.79%
PART	27.37%	33.79%	11.03%	30.61%	32.20%

IDLE REGENERATION TEST
NON CATALYZED VS CATALYZED TRAPS

BUS RPM	ACCESSORY	RESULTS CATALYZED	RESULTS NON-CAT
600	ON	PASSED	FAILED
600	OFF	PASSED	FAILED
950	ON	PASSED	FAILED
950	OFF	PASSED	PASSED
600	ON	PASSED	FAILED

NEW YORK CITY TRANSIT AUTHORITY

PARTICULATE EMISSIONS NY BUS CYCLE



EMISSION RESULTS NON CATALYZED TRAPS
% DEGRADATION BUS #4517 TEST #1 AND #2

	<u>TEST #1</u>	<u>TEST #2</u>	<u>% DEGRADATION</u>
THC	8.583	8.049	-6.2%
CO	8.799	8.555	-2.8%
NOx	73.637	65.732	-12%
PART	0.606	2.074	70%

EMISSION RESULTS CATALYZED TRAPS

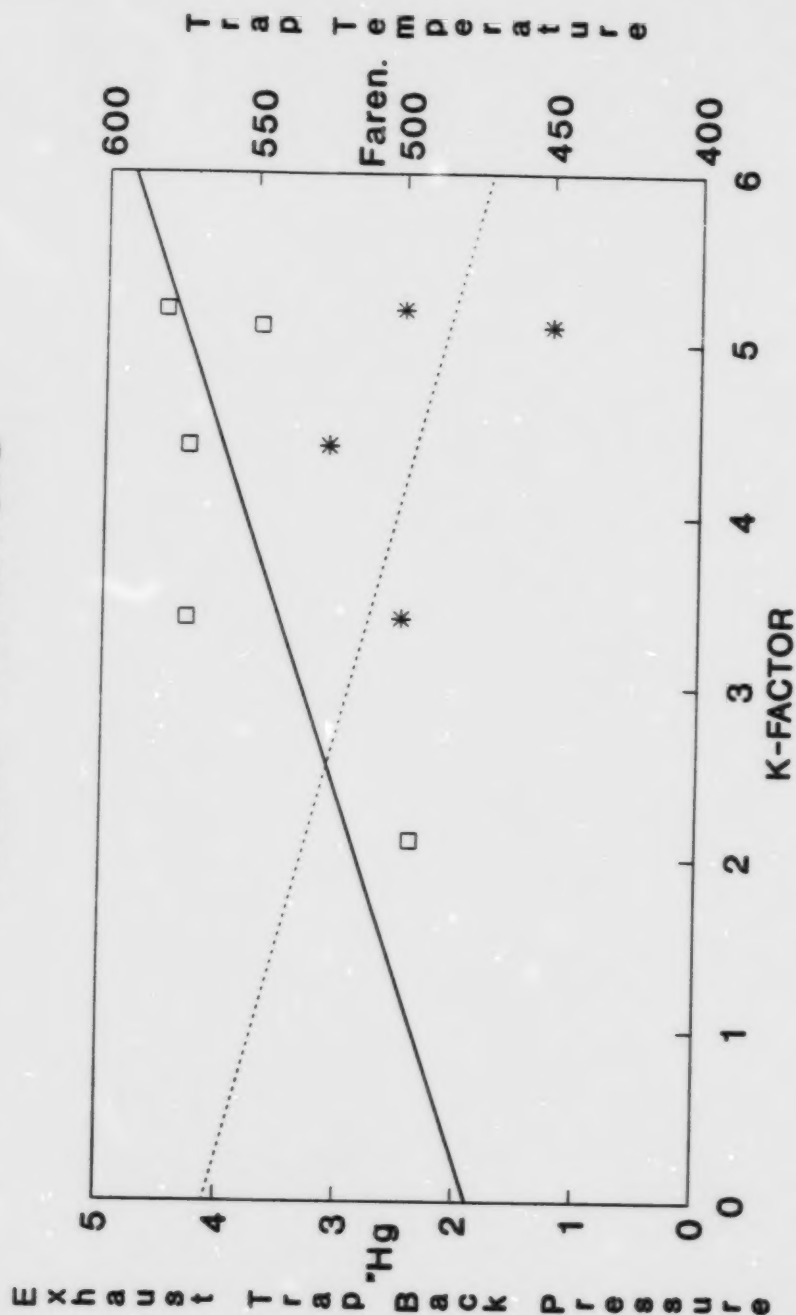
BUS #4517 DCI SYSTEM

	<u>BASELINE</u>	<u>CATALYZED TRAPS</u>	<u>% REDUCTION</u>
THC	8.897	6.624	25.54%
CO	9.091	4.453	51.02%
NOx	73.541	63.991	12.99%
PART	1.645	1.464	11.03%

TREND ANALYSIS

[illegible]

TRAP OXIDIZER BUS #4517 TREND ANALYSIS

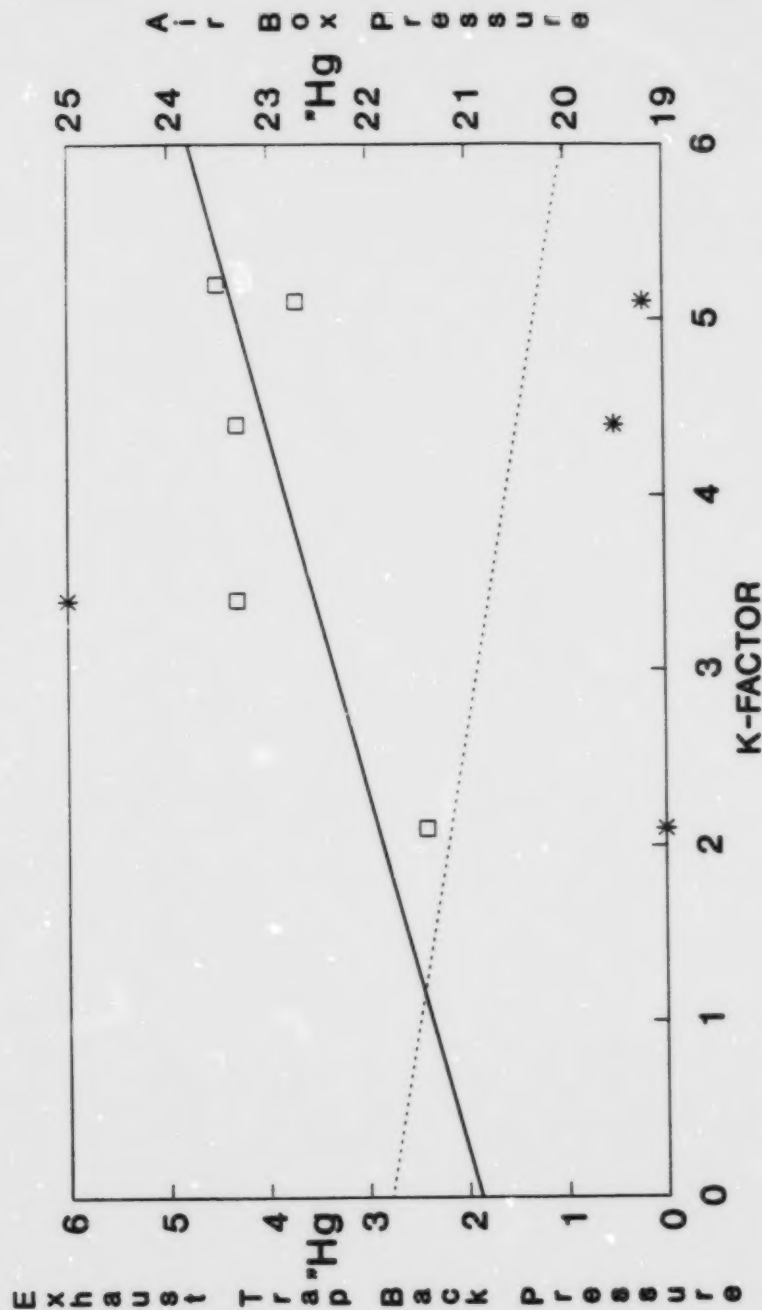


—□— (K-factor,exhaust) *... (K-factor,temp)

Readings obtained maximum locked wheel load (i.e. in gear full throttle service brakes applied)

K-8PTMP.CHT

TRAP OXIDIZER BUS #4517 TREND ANALYSIS



—□— (K-factor, exhaust) *... (K-factor, air box)
Readings obtained maximum locked wheel load (i.e. in gear full throttle service brakes applied)

K-SPAIR.GHT

LEGEND

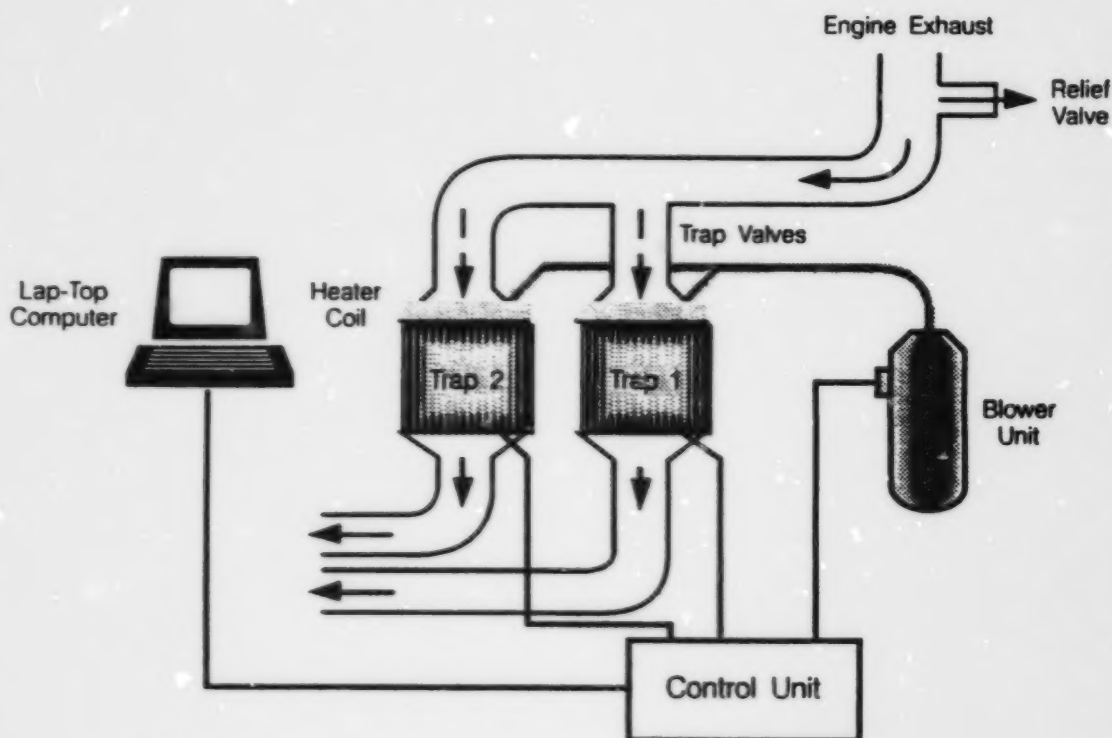
All testing was conducted over the EPA Transient Test Cycle.

1981	-	1981 Detroit Diesel 6V92TA Baseline Testing #1
1982	-	1981 Detroit Diesel 6V92TA Baseline Testing #2
1989	-	1989 Detroit Diesel 6V92TA DDEC II Calif Low NO ^x Configuration
100+ ECS	-	1981 Detroit Diesel 6V92TA with Midwest Power 100+ Exhaust Control System
Trap	-	1989 Detroit Diesel 6V92TA DDEC II Calif Low NO ^x Configuration with Donaldson Dual Trap System
EPA	-	1991 EPA transient test cycle for urban buses.

All % numbers indicated on the graphs represent a comparison of emission level to the EPA 1991 urban bus regulations. The comparison assumes EPA to be 100% of allowable emissions.

(1104W)

NYCTA
PRESENTATION TO 1990
WINDSOR WORKSHOP ON
ALTERNATIVE FUELS



TORONTO, ONTARIO
JUNE 11-14, 1990

**TRAP OXIDIZER PROGRAM
NEW YORK CITY TRANSIT AUTHORITY**

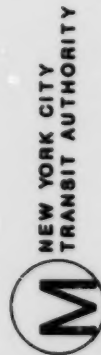
**1990 WINDSOR WORKSHOP ON
ALTERNATIVE FUELS**

TECHNICAL SUPPORT

CLEAN DIESEL TECHNOLOGIES

WAYS TO MEET THE 1991 FEDERAL EMISSION STANDARDS

- FUELS AND OILS
 - LOW SULFUR FUEL
 - LOWER AROMATICS
 - LOW ASH CONTENT OIL
 - POSSIBLE USE OF FUEL ADDITIVES
- ENGINE MODIFICATIONS
 - COMBUSTION CHAMBER DESIGN
 - FUEL INJECTOR OPTIMIZATION
 - ACCELERATION DELAY DEVICES
- EXHAUST AFTERTREATMENT
 - CATALYTIC TRAP OXIDIZERS
 - FLOW TROUGH OXIDATION CATALYSTS
 - ELECTROSTATIC AGGLOMERATOR
 - DIESEL PARTICULATE FILTER
 - VARIOUS MATERIALS
 - VARIOUS REGENERATION METHODS



NO. 1 DIESEL FUEL SPECIFICATIONS

PHYSICAL AND CHEMICAL REQUIREMENTS

PROPERTIES	LIMITS	TEST
FLASH POINT DEGREES F MIN	100	D-93
POUR POINT DEGREES F. MAX	0	D-97
VISCOSITY S.U. AT 100 DEGREES F. MAX	34.4	D-445 & D-2161
INITIAL BOILING POINT DEGREES F. MIN	325	
90% RECOVERY DEGREES F. MAX	530	
FINAL BOILING POINT DEGREES F. MAX	580	
COLOR A.S.T.M.	3/4 -2	D-155
CORROSION COPPER, 3 HOURS AT 212 F	MAX 1-A	D-130
ODOR	SATISFACTORY	
ALKALI OR MINERAL ACIDS	NEUTRAL	D-974
WATER AND SEDIMENT % MAX	TRACE	D-96
CARBON RESIDUE % MAX	.05	D-189
SULPHUR % MAX	.05	D-1266 & D-1552
CETANE NO. MIN	48	D-613



NEW YORK CITY
TRANSIT AUTHORITY

EXHAUST AFTERTREATMENT

- CATALYTIC TRAP OXIDIZERS
FLOW THROUGH OXIDATION CATALYST
- ELECTROSTATIC AGGLOMERATOR
- DIESEL PARTICULATE FILTER
 - VARIOUS MATERIALS
 - CORDIERITE WALL FLOW MONOLITH
 - CERAMIC FOAM - SILICON CARBIDE
 - FIBER COIL CERAMIC SUBSTRATE
- VARIOUS REGENERATION METHODS
 - MICROWAVE REGENERATION
 - PASSIVE REGENERATION
 - RESERVOIR PARTICULATE TRAP SYSTEM
 - DIESEL FUELED BURNER
 - ELECTRIC HEATER COIL
 - CERIUM INJECTION

NEW YORK CITY TRANSIT AUTHORITY

TECHNICAL SERVICES REPORT:

FIELD EVALUATION OF PARTICULATE TRAP OXIDIZERS

The New York City Transit Authority:

- Operates a fleet of 3580 buses
- On 229 routes in all five boroughs.
- Each year these buses travel over 100 million miles
- At an average speed of 6.7 (Miles per engine hour).
- The operating budget for the calendar year is \$860 million.

Air quality in New York City is a major problem. The NYCTA is committed to reducing its contribution to the problem, so we can remain the clean air alternative!

Surface Transit's primary contribution to the air quality problem is diesel particulate matter.

During the last ten years the New York City Department of Environmental Protection has quantified our problem. On average, a typical bus traveling 180 miles a day emits about 1 lb. of particulates. If you extrapolate this number using the operating statistics just presented, you will have a good idea of the magnitude of the problem.

One way of dealing with this bus emission problem is through the use of exhaust after treatment.

Specifically in this case we refer to a trap oxidizer system.

- Bus 1698 was equipped by Ortech International with the prototype Trap Oxidizer System installed in March of 1989.
- After a shakedown, inspection and system break-in period, the bus entered revenue service on the M15 route in Manhattan.

The M15 route was chosen for the Trap Demonstration Program because of its difficult duty cycle, that is:

- Low ground speed
- High passenger density
- High frequency of stops per mile

This route also operates in areas of Manhattan where a significant air pollution problem exists.

Since the bus entered the field evaluation portion of the demonstration program, a daily performance record for bus 1698 and 10 control buses has been collected and evaluated. In addition, any unusual conditions noted by the operator while the bus was in service or detected during routine maintenance inspection were verified and addressed.

From April 3, 1989 - February 4, 1990, bus 1698 accumulated:

- ° 14,600 miles
- ° 2337 engine hours
- ° With an average ground speed of 6 MPEH
- ° Had a fuel economy of 2.12 MPG
- ° Oil consumption was 700 MPQ
- ° The trap system accumulated 4575 regeneration cycles.

The control fleet of 10 similarly configured RTS 04 buses had an average accumulation of:

- ° 19,500 miles per bus
- ° An average ground speed of 8 MPEH
- ° A fuel economy of 2.5 MPG
- ° Oil consumption averaged 550 MPQ

The accumulated mileage differential of 23% between the trap equipped bus and the control fleet is significant and requires explanation. The differential can be attributed to the following factors:

- ° The trap equipped bus undergoes routine testing at the New York City Department of Environmental Protection emission test cell on a regular basis.
- ° The trap equipped bus is routinely removed from service for trap system demonstrations.
- ° Since only one trap equipped bus existed for most of the evaluation period, system optimization, troubleshooting and enhancements required additional out-of-service time.

FUEL ECONOMY DIFFERENTIAL

The fuel economy differential between the trap equipped bus and the control fleet was 14.6%. This penalty exceeds the 3 to 6% fuel penalty which had been anticipated prior to the field evaluation. The reasons for the excessive differential were:

- **DEMONSTRATION TIME** - a significant amount of idle time has been accumulated on the trap bus, especially during demonstration programs. Interest in the trap program has been high, but this interest has impacted revenue service time and has increased the fuel consumption penalty.
- **PRESENT DIESEL BURNER CONFIGURATION** - The diesel burner used on bus 1698 is a modified off-the-shelf burner identical to those used as coolant heaters or truck operators cab heaters.

The burner for the trap system is located in the engine compartment under the air cleaner housing and over the transmission.

The burner is required to deliver the heat necessary to start regeneration in a ceramic trap about 10 feet away and around a 90° corner. Obviously, this will require more energy than a system where the burner is located adjacent to or integrated into the trap housing itself; however this is a prototype system designed to demonstrate the potential of a trap oxidizer system in a transit bus application, not a production system.

REGENERATION INTERVAL - One of the program goals was to maximize the number of regeneration cycles to obtain reliability data on the traps themselves.

The current loading time for the trap system is 30 minutes per unit. This requires that the burner be on 18.3 minutes per hour.

A typical bus will produce about 2.5 grams/mile of particulates. Trap optimum regeneration will occur with the trap about 50% loaded or at 20 grams of particulates. This represents about 1 hour. and 30 minutes of loading time even in our duty cycle. Therefore, we could reduce the frequency of our regeneration cycles and related fuel consumption significantly, bringing us very close to the calculated values.

PROBLEMS - The trap oxidizer system on bus 1698 has exhibited some problems. The problems are in two major classes:

- System Problems
- Reliability Issues

THE SYSTEM RELATED PROBLEMS ENCOUNTERED WERE:

BURNER PHOTO OPTICAL FLAME DETECTION SENSOR

The purpose of this sensor is to have a safety device to ensure that fuel flow through the burner nozzle only occurs when a flame is present. Beginning last June, when high temperatures were experienced, the trap diagnostic system recorded burner fault conditions. These conditions could be caused by insufficient burner voltage or a defect in the photo-electric flame sensor. Separation of the burner head from the combustion chamber indicated that the optical sensor was clouded with soot.

Possible causes of this problem were:

- ° Poor fuel quality
- ° Poor seating of trap/exhaust diverter valves
- ° Non-optimized combustion ratios for the application environment

Problem analysis determined that high temperatures and an installation modification made to the combustion chamber created poor fuel combustion, causing high levels of soot on the optical sensor.

In order to minimize the impact on mileage accumulation from this problem, a program of weekly cleaning of the photo eye during periods of high temperature was incorporated until the burner system could be optimized. The time to perform this function is approximately 7 minutes. per/week. It would be noted that burner optimization on a more recent trap demonstration bus has been accomplished and the impact on the occurrence of photo eye sooting is being monitored.

ELBOW TEMPERATURE SENSOR

On August 30, bus 1698 recorded a "system over-temperature" failure mode. This fault indication was designed to occur if external temperature at the outer radius of the 90° elbow exceeded 135°C. It was assumed that this portion of the heat tube would undergo extreme thermal stress and could be a significant reliability issue. Analysis of the system determined that the thermal sensor in use had failed and no real "system over temperature" had occurred.

The sensor was replaced with one which is typically used in vehicle applications and no further over temperature events occurred on bus 1698, or the 2nd generation trap equipped buses which are equipped with identical sensors.

HEATING PIPE INSULATION- The insulating blanket used to cover the heat tubes has not met the requirements of the system. The insulation blanket has been damaged by normal engine compartment cleaning and has required replacement.

COMPONENT WEATHERPROOFING- Fault indications were recorded in the system at significant over-temperature situations. Analysis of the problem found that water and dirt had entered the thermocouple junction box, oxidizing components. A new box was made and no further problems have occurred.

MANNER OF TREATING OVERLOADED TRAP MONOLITH

During the demonstration period one trap failure occurred. The trap failure occurred during a manual regeneration.

A careful analysis of this failure was performed. Our findings were:

- ° Bus 1698 was checked on Monday August 7, 1989, prior to entering normal revenue service and was found in "E-stop." When an E-stop condition exists on the trap system, an audible signal from a horn should occur at intervals to alert the bus operator to a trap system problem.
- ° A review of depot records found that bus 1698 had been reported for an unknown buzzer by a bus operator on Saturday August 5, 1989. Depot maintenance personnel, not familiar with the trap system, disconnected the time delay horn relay and returned the bus to service. The bus accumulated an additional 139 miles with the trap system disabled.

On Monday, when personnel familiar with the trap system found the bus in E-stop, they proceeded with normal troubleshooting procedures which included manual regeneration. During this regeneration, thermal runaway occurred.

The thermal runaway occurred because the trap system had accumulated an estimated particulate load of 174 grams during the 139 miles and 23 engine hours. In order to prevent recurrence of this condition, the following changes were made:

- Circuit logic was reversed and the relay was epoxied in place to insure safe failures.
- Control program has been modified to indicate elapsed time that trap system is in fault.
- Depot personnel were retrained on alarm and signal circuit for trap system.
- Additional decals were installed in the electrical apparatus box.
- Troubleshooting procedures have been modified to insure manual regenerations are not conducted on traps with more than eight hours of accumulation time without special precautions.

The estimated loading was derived from New York City Department Environmental Protection data for the engine in bus 1698 prior to trap installation. In addition, failure analysis of trap performed by Corning reached a similar conclusion.

THE RELIABILITY ISSUES ENCOUNTERED WERE:

- Maintenance Intervals
- Life Of System Components
- Impact Of Related Bus Subsystems

MAINTENANCE INTERVALS

The particulate trap oxidizer system has required no change to established preventive maintenance intervals. Currently all buses receive a quality assurance inspection daily and receive detailed mechanical inspections every 3,000 miles.

We have seen no indication that use of a particulate trap oxidizer system will require this to change.

LIFE OF SYSTEM COMPONENTS AND IMPACT OF RELATED BUS SUBSYSTEMS

The demonstration bus has not experienced component failures which could be attributed to the trap system. The only engine unit failure which occurred was a water pump seal on bus 1698. This is a common failure.

Spectrochemical oil analysis is a normal part of our preventive maintenance inspection. The oil conditions found on the trap bus were similar to non-trap equipped overhauled engines, that is high silicon readings for the first 6000-9000 miles.

Exhaust back pressure was checked weekly to insure no changes were occurring due to increasing efficiency of the trap system.

RECOMMENDATIONS:

The data accumulated from bus 1698, as well as the three additional trap oxidizer equipped buses, have led to the following recommendation:

- Expansion of demonstration programs using various regeneration methods as well as alternative substrates is needed to clearly define all the reliability and durability issues which may occur.
- The diesel burner must be optimized to improve reliability and reduce its impact on fuel consumption.
- More data is needed to determine the full impact that particulate trap oxidizer systems will have on transit operations and clearly define the maintenance and durability issue.

The New York City Transit Authority has purchased 400 buses which will be equipped with a particulate trap oxidizer system designed to meet the 1991 emission requirements. This large scale demonstration will provide the information necessary to meet 150,000/290,000 mile maintenance/durability requirement of the federal emission rules.

CONCLUSIONS:

What conclusions has this demonstration led to:

- Bus 1698 to date: 60 weeks of revenue service
(June 6, 1990) 21,287 miles
3,371 engine hours
5,541 trap regeneration cycles
2.15 miles per gallon average

- Bus 4511 to date: 33 weeks of revenue service
(June 6, 1990) 10,774 miles
1852 engine hours
3,185 trap regeneration cycles
2.38 miles per gallon average
- Bus 4512 to date: 32 weeks of revenue service
(June 6, 1990) 11,726 miles
1850 engine hours
3,571 trap regeneration cycles
2.25 miles per gallon average
- Bus 4517 to date: 17 weeks of revenue service
(June 6, 1990) 4420 miles
776 engine hours
120 trap regeneration cycles
2.49 miles per gallon average
- Particulate emissions reduced by over 80 percent
- Carbon monoxide reduced by 50 percent
- Small reduction in oxides of nitrogen
- No deterioration in trapping efficiency to date
- Particulate trap oxidizer system is technology that can be retrofitted in a standard transit bus.
- With the inclusion of the recommended improvements, particulate trap oxidizer systems are a viable, cost-effective way of reducing emissions from urban transit buses
- With further development, a particulate trap oxidizer system will meet the 1991 US Environmental Protection Agency emission standards for urban buses

NEW YORK CITY TRANSIT AUTHORITY

TRAP OXIDIZER PROGRAM PROJECT DATABASE

TECHNICAL SERVICES

% EMISSION REDUCTIONS USING TRAP SYSTEM **PHASE IIA**

<u>EMISSION</u>	BUS #4511 TEST #			BUS #4512 TEST #		
	1	2	3	1	2	3
PARTICULATE	82	93	82	91	90	84
CO	33	67	68	57	55	48
THC	16	38	42	14	17	45
NOX	0	5	22	0	1	19

NEW YORK CITY TRANSIT AUTHORITY

LEGEND

- THREE TESTS WERE COMPLETED AT THE NEW YORK CITY DEP EMISSIONS LAB IN BROOKLYN, NEW YORK
- TWO TESTS WERE CONDUCTED USING NON-CATALYZED TRAPS (JAN 22/ 23. 1990 AND MARCH 26/27, 1990)
- ONE TEST WAS COMPLETED USING CATALYZED TRAP (MARCH 28,1990)
- PERCENT REDUCTIONS NUMBERS WERE CALCULATED BASED ON THE FOLLOWING FORMULA;
$$(\text{BASELINE} - \text{TEST}) / \text{BASELINE} \cdot 100$$
- TRAP #1- DRIVERS SIDE OF THE BUS
- TRAP #2- DOOR SIDE OF THE BUS

NY-BUS CYCLE

DONALDSON SYSTEM				NYCTA BUS #4517			
	BASELINE AVG	NON CATALYZED TEST #1	% REDUCTION	NON CATALYZED TEST #2	% REDUCTION	CATALYZED TRAP TEST #1	% REDUCTION
THC	8.897	8.583	3.53%	8.044	9.58%	6.624	25.54%
CO	9.091	8.799	3.22%	8.555	5.90%	4.453	51.02%
NOx	73.541	73.637	-0.13%	65.732	10.62%	63.991	12.99%
PART	1.645	0.606	63.16%	2.074	-26.08%	1.464	11.03%

3-M SYSTEM SEPTA BUS			
	BASELINE AVG	SYSTEM AVG	% REDUCTION
THC	6.9855	7.2245	-3.42%
CO	9.5905	10.925	-13.91%
NOx	60.1545	62.574	-4.02%
PART	1.1595	0.4515	61.06%

BASELINE EMISSION TEST RESULTS
NOVEMBER 27 and 28, 1989
GRAMS/MILE

BASELINE #1 VALUES

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.054	3.846	8.826	4.013	3.930
CO	3.33	3.991	8.797	4.112	4.052
NOx	27.936	33.018	73.306	32.444	32.731
PART	0.768	0.885	1.617	0.922	0.904

BASELINE #2 VALUES

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.197	3.961	8.967	4.03	3.996
CO	3.648	4.184	9.385	4.298	4.241
NOx	27.395	32.291	73.779	32.254	32.273
PART	0.847	0.935	1.673	0.875	0.905

AVERAGE OF BOTH BASELINE #1 AND #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.126	3.904	8.897	4.022	3.963
CO	3.489	4.088	9.091	4.205	4.146
NOx	27.666	32.655	73.541	32.349	32.502
PART	0.808	0.910	1.645	0.899	0.904

ANALYZED EMISSION TEST RESULTS JANUARY 22 and 23, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.309	3.829	8.294	3.84	3.835
CO	3.452	3.851	8.858	4.183	4.017
NOx	28.4274	30.873	73.601	31.858	31.366
PART	0.844	0.514	0.665	0.578	0.546

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.088	3.943	8.871	4.03	3.987
CO	3.399	4.141	8.739	4.126	4.134
NOx	28.583	32.334	73.672	32.239	32.287
PART	0.415	0.428	0.547	0.458	0.443

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.199	3.886	8.583	3.935	3.911
CO	3.426	3.996	8.799	4.155	4.075
NOx	28.505	31.604	73.637	32.049	31.826
PART	0.630	0.471	0.606	0.518	0.495

NON-CATALYZED EMISSION TEST RESULTS

MARCH 26 and 27, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	3.035	3.556	8.242	3.614	3.585
CO	3.366	3.833	8.327	3.742	3.788
NOx	26.298	29.206	66.595	29.086	29.146
PART	0.873	0.741	2.414	0.643	0.692

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.853	3.562	7.846	3.576	3.569
CO	3.544	4.073	8.783	4.117	4.095
NOx	26.197	29.257	64.868	28.542	28.900
PART	0.877	0.757	1.734	0.705	0.731

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.944	3.559	8.044	3.595	3.577
CO	3.455	3.953	8.555	3.930	3.941
NOx	26.248	29.232	65.732	28.814	29.023
PART	0.875	0.749	2.074	0.674	0.712

CATALYZED EMISSION TEST RESULTS

MARCH 28, 1990

GRAMS/MILE

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.121	2.78	6.809	2.717	2.749
CO	1.789	2.3	4.663	2.048	2.174
NOx	25.567	28.405	64.385	27.973	28.189
PART	0.648	0.659	1.701	0.681	0.670

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.023	2.944	6.439	2.745	2.845
CO	1.417	2.393	4.242	2.3	2.347
NOx	25.804	28.825	63.596	28.179	28.502
PART	0.525	0.546	1.226	0.566	0.556

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	2.072	2.862	6.624	2.731	2.797
CO	1.603	2.347	4.453	2.174	2.260
NOx	25.686	28.615	63.991	28.076	28.346
PART	0.587	0.603	1.464	0.624	0.613

% REDUCTIONS FROM BASELINE
(USING A NON-CATALYZED TRAP)
JANUARY 22 and 23, 1990

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	-6.01%	1.94%	6.83%	4.52%	2.42%
CO	1.11%	5.93%	2.65%	0.54%	0.85%
NOx	-2.73%	5.40%	-0.08%	1.51%	4.17%
PART	-4.75%	44.75%	60.61%	34.76%	39.57%

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	1.20%	-1.01%	0.29%	-0.21%	0.23%
CO	2.58%	-1.31%	3.87%	1.88%	2.53%
NOx	-3.32%	0.98%	-0.18%	0.34%	-0.04%
PART	48.61%	52.97%	66.75%	49.03%	51.05%

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	-2.34%	0.45%	3.53%	2.15%	1.30%
CO	1.82%	2.24%	3.22%	1.20%	1.72%
NOx	-3.04%	3.22%	-0.13%	0.93%	2.07%
PART	22.04%	48.24%	63.16%	42.35%	45.30%

REDUCTIONS FROM BASELINE
(USING A CATALYZED TRAP)
MARCH 28, 1990

TRAP #2

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	35.27%	24.58%	27.62%	31.74%	28.16%
CO	59.39%	41.46%	53.34%	45.30%	43.38%
NOx	6.73%	11.73%	13.52%	12.69%	12.31%
PART	34.98%	40.00%	25.47%	37.01%	38.50%

TRAP #1

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	32.14%	28.78%	23.46%	32.44%	30.61%
CO	48.72%	43.73%	48.71%	51.30%	47.51%
NOx	7.99%	13.01%	12.45%	13.53%	13.27%
PART	19.75%	27.58%	-3.40%	24.21%	25.89%

AVERAGE OF BOTH TRAPS

	CBD	NYBC-A	NYBUS	NYBC-B	NYBC AVG
THC	33.71%	26.68%	25.54%	32.09%	29.39%
CO	54.06%	42.99%	51.02%	48.30%	45.45%
NOx	7.16%	12.37%	12.99%	13.21%	12.79%
PART	27.37%	33.79%	11.03%	30.61%	32.20%

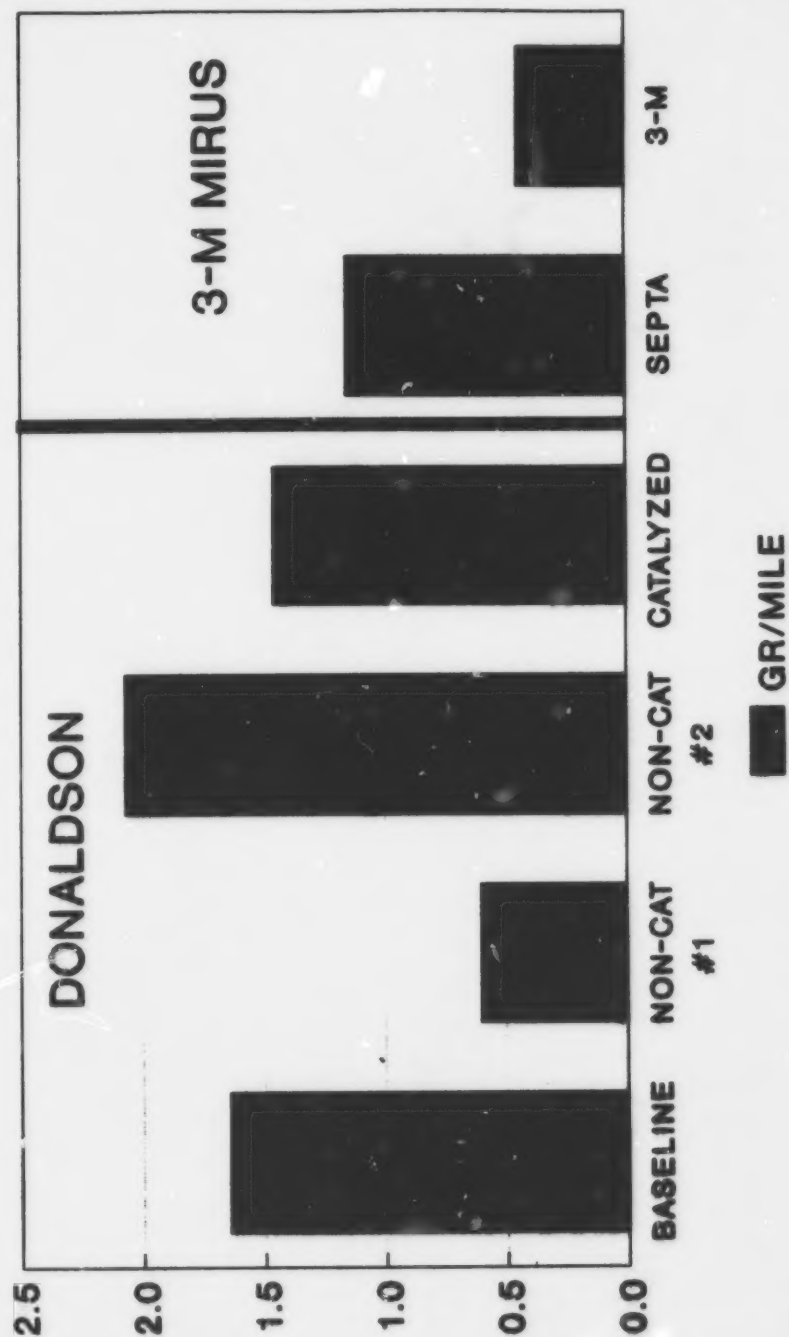
IDLE REGENERATION TEST **NON CATALYZED VS CATALYZED TRAPS**

BUS RPM	ACCESSORY	RESULTS CATALYZED	RESULTS NON-CAT
600	ON	PASSED	FAILED
600	OFF	PASSED	FAILED
950	ON	PASSED	FAILED
950	OFF	PASSED	PASSED
600	ON	PASSED	FAILED

NEW YORK CITY TRANSIT AUTHORITY

PARTICULATE EMISSIONS

NY BUS CYCLE



EMISSION RESULTS NON CATALYZED TRAPS
% DEGRADATION BUS #4517 TEST #1 AND #2

TEST #1 TEST #2 % DEGRADATION

THC	8.583	8.049	-6.2%
CO	8.799	8.555	-2.8%
NOx	73.637	65.732	-12%
PART	0.606	2.074	70%

NEW YORK CITY TRANSIT AUTHORITY

EMISSION RESULTS CATALYZED TRAPS
BUS #4517 DCI SYSTEM

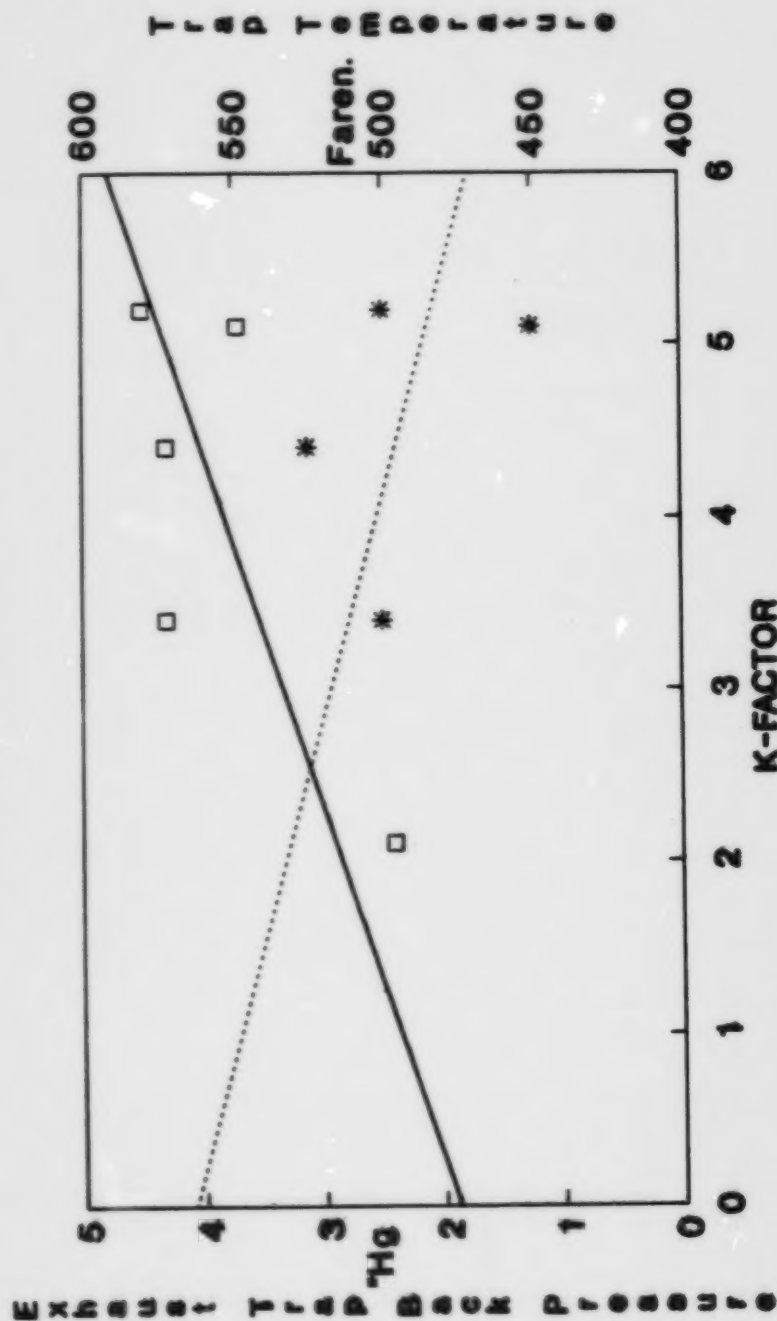
	<u>BASELINE</u>	<u>CATALYZED TRAPS</u>	<u>% REDUCTION</u>
THC	8.897	6.624	25.54%
CO	9.091	4.453	51.02%
NOx	73.541	63.991	12.99%
PART	1.645	1.464	11.03%

NEW YORK CITY TRANSIT AUTHORITY

TREND ANALYSIS

[illegible]

TRAP OXIDIZER BUS #4517 TREND ANALYSIS



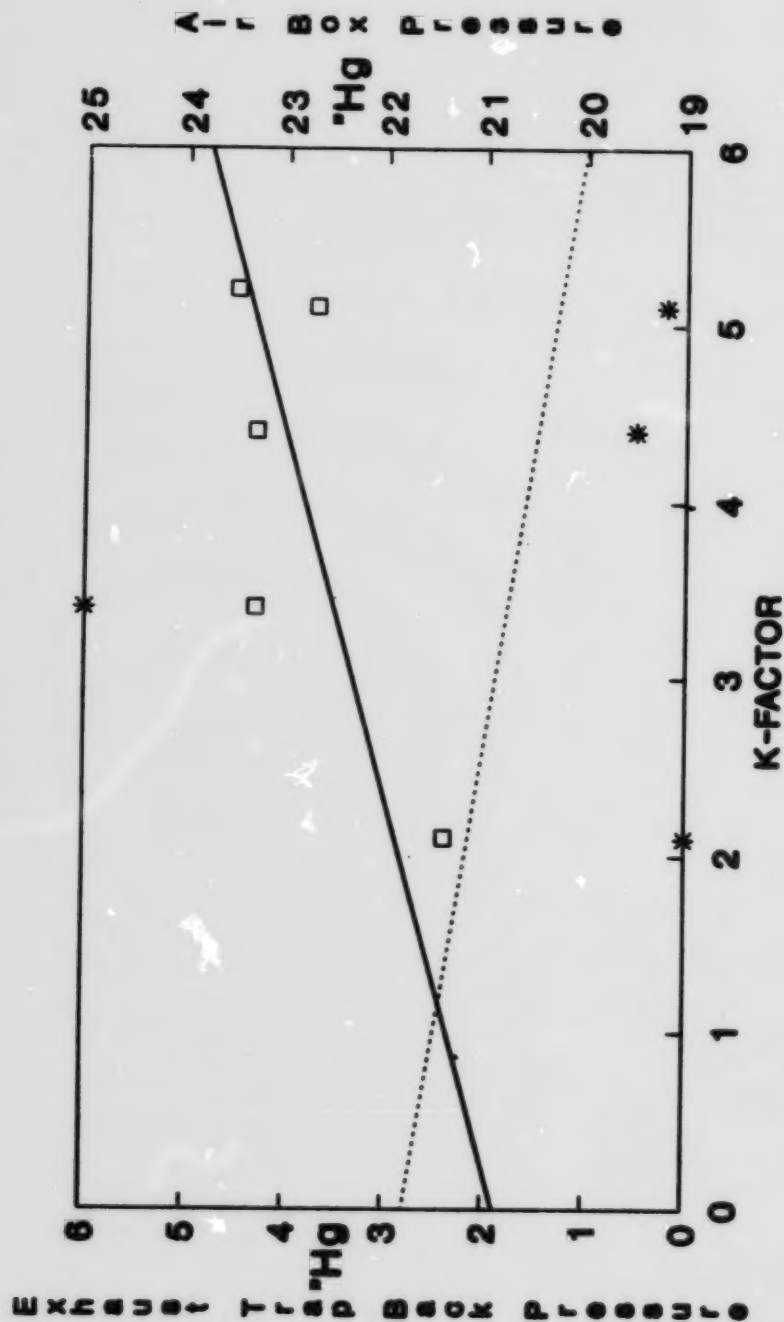
—□— (K-factor,exhaust)

....*.... (K-factor,temp)

Readings obtained maximum locked wheel load (i.e. in gear full throttle service brakes applied)

W-SP-TEMP.GNT

TRAP OXIDIZER BUS #4517 TREND ANALYSIS



—□— (K-factor, exhaust) *..... (K-factor, air box)
Readings obtained maximum locked wheel load (i.e. in gear full throttle service brakes applied)

K-EMIA.GHT

EPA TRANSIENT CYCLE

CALCULATIONS OF REGENERATION EMISSION TIME
APPROX. 2 REGENS PER 17 HOUR DRIVING TIME

<u>.5 Hours</u>	<u>16.5 Hours</u>
17	17
3%	97%

3% Regen time over duty cycle.

EPA TRANSIENT CYCLE

ENGINE - 1989 DDEC II 6V92TA CALIF. LOW NO^x
TEST - DONALDSON DUAL TRAP SYSTEM

	HC	NO ^x	CO	PART
Hot	.66	4.92	2.62	.043
Cold	.67	4.78	3.06	.115
1/7 Hot	.583	4.226	2.24	.037
6/7 Cold	.096	.6829	.437	.0164
Weighted	6.79	4.909	2.68	.0534
Regen	.66	5.01	2.66	.056
Weighted 97%	.6586	4.762	2.599	.0518
Regen 3%	.018	.1503	.0798	.00168
True Emission	.68	4.91	2.68	.053

EPA STANDARDS

	HC	NO^x	CO	PART
1991 Urban Bus	1.3	5.0	15.5	0.10

SESSION 4 - ECONOMICS AND INFRASTRUCTURE

Co-Chairs: John Hutchinson, Ontario Ministry of Energy.
Jerry Allsup, U.S. Dept. of Energy

COST EFFECTIVENESS OF ALTERNATIVE FUELS FOR CANADIAN TRANSIT OPERATIONS

M.BOL, M.KIRSHENBLATT, G.MACKEVIC

SYMPHER: MUELLER International Inc.
Ottawa

SPONSORED BY ENERGY MINES AND RESOURCES

PURPOSE OF THE STUDY

**determine the incremental costs and environmental
benefits associated with implementing
alternative fuels in major Canadian transit fleets**

ALTERNATIVES CONSIDERED

- **conventional diesel**
- **low - sulphur diesel with particulate traps**
- **methanol**
- **natural gas**
- **gasoline**

INCREMENTAL COSTS

- **additional costs relative to conventional diesel**
- **normal fleet replacement**
- **economic costs excluding taxes; financial costs including taxes**

ENVIRONMENTAL BENEFITS

- **reductions in regulated vehicle emissions**
- **fuel production emissions**
- **changes in carbon dioxide**

MAJOR COST FACTORS AND ASSUMPTIONS

GENERAL

- **demonstration and commercial engines**
- **documented emissions results**
- **unit facilities of 200 buses**
- **outdoor fuelling for gasoline, natural gas and
methanol**
- **changes in passenger carrying capacity**

Overloaded TTC buses major cause of Metro road damage, study finds

By Peter Howell Toronto Star
Illegally overloaded Toronto Transit Commission buses are the major cause of damage to Metro roads, a study obtained by The Star says.

The study, by the Metro roads and traffic department, says the TTC's nearly 1,700 buses, when fully loaded with rush hour crowds, violate the provincial Highway Traffic Act rules governing maximum axle weights.

In the case of a fully loaded bendable bus — the large model used on busier routes — the front-end weight exceeds provincial regulations by 62 per cent, the study found.

The excess weight causes "rutting" that is very expensive to repair, especially in curb lanes and bus bays. And it's a major safety problem, because the ruts cause cars to go out of control.

The damage caused by the buses exceeds \$1 million a year, said Tom Johnston, Metro's chief roads maintenance engineer. The department had asked for \$35 million from the province for resurfacing and rebuilding of Metro roads this year but the province provided only \$25 million.

The ruts are also the cause of the "intolerable nuisance" of pedestrians being splashed by vehicles in curb lanes on rainy days, the study says.

The report calls for drastic measures to be taken, with options

ranging from buying a new fleet of buses, limiting passenger loads, changing the law to make TTC buses legal or increasing provincial road repair subsidies.

Yesterday, TTC officials admitted the commission is violating the law with excessive bus weights, but said the problem exists for transit firms in Ottawa, London, Ont. and throughout North America.

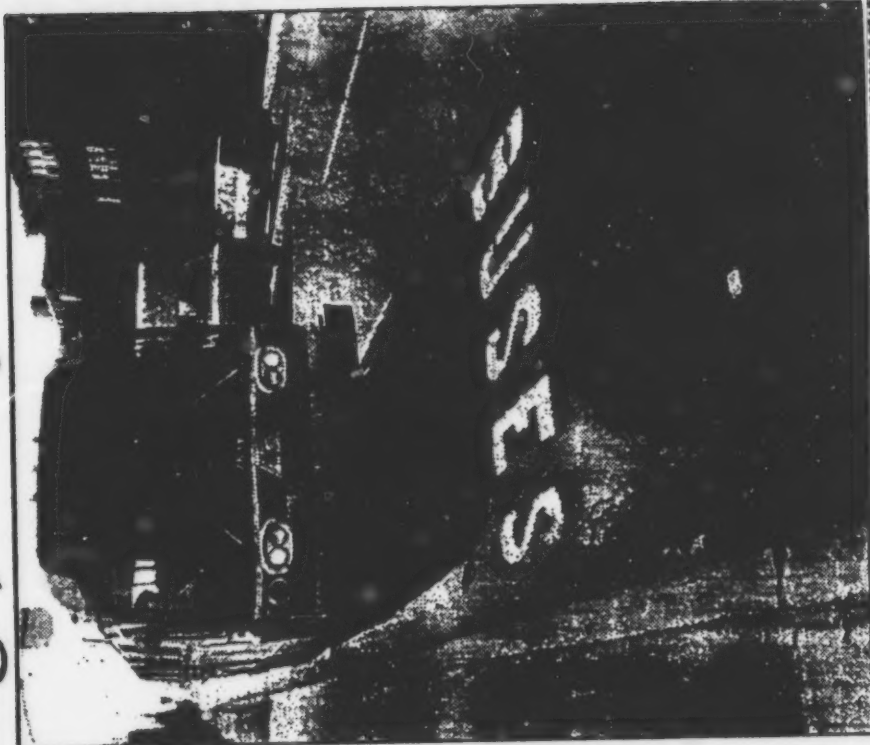
"I don't question that our wheel loads exceed the weight limits set out by the (transport) ministry but the ministry knows that," said Don Morton, the TTC's general manager of engineering and maintenance.

"It's not a unique situation either for Toronto or the TTC," he said. He added he's only seen a draft of the study and couldn't comment on it in detail.

Deputy transport minister David Hobbs said he's also familiar with the report, but "it draws certain conclusions we really haven't gotten into in any depth at this point."

The legal maximum for a front axle weight of a bus or truck is 48.9 kilonewtons (a unit of measurement that combines weight and motion) while the bendable buses clock in at 78.3 kilonewtons when fully loaded.

The traditional 40-foot bus also exceeds the provincial maximum, weighing in at 53.3 kilonewtons when loaded.



JOHN MANKIN/TORONTO STAR

CRACKED ROAD: Ruts caused by illegally overloaded TTC buses cost Metro more than \$1 million in road repairs and can be a hazard to drivers, a Metro study says.

MAJOR COST FACTORS AND ASSUMPTIONS

CONVENTIONAL DIESEL (Baseline)

- change from DDC 6V71N to DDC 6V92TA to meet Canadian 1988 emissions standards
- EMR forecast of fuel prices
- \$0.26 per litre in 1990, \$0.33 in 2005 (excluding taxes)

PARTICULATE TRAPS

- \$5000 with a life of 290,000 km
- 6% increase in fuel consumption; 3 cent increase per litre of fuel

NATURAL GAS

- **mechanical fuel systems (Iveco 8820 and Cummins L10)**
- **additional \$18,000 for the vehicle**
- **\$3 million for facilities**
- **additional weight of 1200 kg for aluminum fuel storage tanks; range of 600 km**
- **\$0.10 per cubic metre in 1990; \$0.17 in 2005**

METHANOL

- **methanol 6V92TA engine @ \$6000**
- **\$200,000 for infrastructure**
- **additional weight of 400 kg; range of 800 km**
- **\$0.15/litre FOB Edmonton in 1990; \$0.10 as transportation fuel**

GASOLINE

- **Ford 7.0 l engine; \$7000 decrease in vehicle costs**
- **\$175,000 in infrastructure**
- **\$0.27 per litre in 1990; \$0.35 in 2005**

VEHICLE EMISSIONS

- **documented data for regulated emissions**
- **estimated in gm/km**
- **CO₂ estimated from simplified combustion equation**

ENGINE EMISSIONS

(g/kw - hr)

	HC	CO	NOx	Part
Diesel - 6V71N	0.47	7.98	11.3	0.61
Diesel - 6V92TA	0.99	1.78	6.81	0.45
Methanol				
- Demo	1.03	12.1	1.70	0.11
- Research	0.74	0.6	3.1	0.10
Natural Gas				
- Demo	2.14	1.70	22.9	0.04
- Research	1.7	0.3	6.0	0.07
Gasoline	2.01	38.9	5.38	0.11
1988 Cdn Standard	1.74	20.8	8.04	0.80
Proposed 1991	1.74	20.8	6.7	0.13

SCENARIOS ASSESSED

Field Demonstration Engines - Weight Constraints

- Reduced Weight

Constraints

- No Weight Limitation

Research Engines

- Weight Constraints

- Reduced Weight

Constraints

- No Weight Limitation

MAJOR FINDINGS

(Vancouver)

BEST IMPROVEMENT IN NEWER DIESEL

TECHNOLOGY (change from 6V71N to 6V92TA)

- **Improved fuel consumption**
- **Improved CO, NOx, and Particulate emissions**
- **8000 tonne reduction**
- **\$150/tonne**
- **required for 1988 Canadian standards**
- **does not meet 1991 US standards**

PARTICULATE TRAPS

(Vancouver)

- **Total (NPV) cost of \$8 million**
- **\$31,000 per tonne assuming only particulate reduction**
- **If successfully developed, could be a low cost option to meet 1991 regulations**
- **durability needs to be demonstrated**

NATURAL GAS

(Vancouver)

WITH WEIGHT CONSTRAINTS

- **158 additional buses**
- **total cost is high (\$99 million)**
- **Increased emissions**

NATURAL GAS

WITH NO WEIGHT CONSTRAINTS AND RESEARCH ENGINE

- **total economic cost is \$4 million**
- **fuel tax savings of \$19 million over 20 years**
- **research engine with catalyst meets 1991 standards**
- **decreased CO and particulate emissions; Increased
HC and NOx emissions**

METHANOL

(Vancouver)

WITH WEIGHT CONSTRAINTS

- **total cost is high (\$57 million)**
- **53 additional buses**
- **increased emissions**

WITH NO WEIGHT CONSTRAINTS AND RESEARCH ENGINE

- **total economic cost is \$21 million with chemical
grade methanol**
- **total cost is \$6 million with transportation grade
methanol**
- **meets 1991 US standards**
- **4000 tonnes emissions reduction (\$1,500/tonnes)**

GASOLINE

(Vancouver)

- **can save weight: increase carrying capacity**
- **total economic cost is \$30 million**
- **increased CO emissions**

FUEL PRODUCTION EMISSIONS

FOR METHANOL

- **CO and NOx reductions during fleet operation
offset by 50% and 25%**

FOR OTHERS

- **less than 10% of fleet emissions**

CARBON - DIOXIDE EMISSIONS

RELATIVE WEIGHTING

- Gasoline	100
- Low Sulphur Diesel	82
- Methanol	84
- Natural Gas	72

SUMMARY AND CONCLUSIONS

Best improvement in diesel technology, required to meet 1988 Canadian Standards but does not meet 1991 US Standards.

Extra Weight for Natural Gas and Methanol could reduce carrying capacity, increase costs and emissions.

If weight restrictions are resolved:

- **Particulate traps could be a reasonable cost alternative if durability is demonstrated and emissions are reduced further.**
- **Natural gas offers substantial savings in fuel taxes - more NOx reduction required.**
- **Methanol could be very cost-effective with fuel grade methanol.**
- **Gasoline is not considered a viable alternative.**

COFA

**CANADIAN OXYGENATED FUELS ASSOCIATION
L'ASSOCIATION CANADIENNE DES CARBURANTS OXYGÉNÉS**

METHANOL FUEL ECONOMICS

Ray Colledge

**6th Annual Windsor Workshop
on Alternate Fuels**

June 14, 1990

(a) Introduction

Good morning. I am speaking on behalf of Celanese Canada, the company I work for, and the Canadian Oxygenated Fuels Association, of which I am Chairman. COFA was founded in 1984 to promote the responsible use of methanol as an alternate fuel.

Just to refresh your memory, there are three methanol suppliers in Canada (SLIDE 1), who together account for approximately 2 MM tonnes of methanol, about one-tenth of the world supply, most of which is exported (SLIDE 2).

Methanol is a clean-burning alternative fuel that is expected to play a significant role in satisfying transportation energy needs in the 1990's. Methanol can be utilized in modified passenger car and heavy duty diesel engines. It provides a viable substitute for oil-based fuels by virtue of its large resource base, since it can be produced from natural gas, coal and, longer term, renewable biomass.

More significantly, methanol provides substantial reductions in tailpipe and evaporative emissions of harmful air pollutants such as carbon monoxide, nitrogen oxides, particulate matter (diesel soot), and the photochemically reactive hydrocarbons which are a precursor to ground level ozone or smog.

In the State of California, there has for some time been a recognition that clean fuels such as methanol can play a significant role in addressing the serious air quality problems that exist in the Los Angeles basin.

While appreciating both the air quality benefits of methanol and the contribution to energy security, a number of questions have been raised as to the cost competitiveness of methanol. For example, the world price of methanol is usually referred to in terms of the cost per gallon in \$U.S. on the U.S. Gulf Coast. Over the last ten years, this price has fluctuated from a low of 22 to a high of 70 cents per gallon. Yet we have to point out the economics of a chemically pure methanol, used to make paint, plastics, plywood, and even pharmaceuticals, will not be the same as a fuel-grade methanol used to drive millions of vehicles.

There is an analogy to the situation a hundred years ago when the major application of crude oil up to that time was very limited, and the transformation of the economics in that industry when it started to provide gasoline and diesel for transportation fuels.

So just as the economics of oil products changed dramatically at the turn of the century, so will the economics of methanol a hundred years later. Consequently, I want all of you to forget about the economics of methanol as it is today, because that is irrelevant when we start to consider methanol as a transportation fuel.

For this purpose, we will utilize the results of a study done by Bechtel, which was conducted under the guidance of a steering committee, on which were represented (SLIDE 3) a number of major oil companies, two California state agencies, and a miscellany of other organizations, including COFA.

(b) Implications of the Bechtel Study

The Bechtel study was conducted over a period of several months, at a cost of \$500,000. The objective was to review the potential to make methanol from natural gas in six world locations with a view to supplying the California transportation market. The six locations chosen were (SLIDE 4), and the study developed the costs associated both with building methanol units in each of these locations and with shipping methanol to bulk storage tanks in Los Angeles.

The units would each be capable of producing 10,000 tonnes of methanol a day, or approximately 3 million tonnes a year. This is four times the size of today's largest units, such as for example, the unit my company operates in Edmonton, Alberta. Cost savings would be achieved as a result of scale, quality and, in particular, in the way product was shipped to market, utilizing pipeline and ocean tankers instead of rail car and small tanker as we have today.

The capital cost of putting a 10,000 tonne a day methanol unit in each of these locations is shown on the next slide (SLIDE 5). You can see that the capital costs associated with the Texas, Canadian and Trinidad locations are very similar, with the Saudi unit a little more expensive, and the Australian and Alaskan locations substantially more expensive.

The transportation costs of moving product from these locations to a bulk terminal in Los Angeles were also developed using fuel type modes of transportation (SLIDE 6).

These transportation costs are shown on the next slide (SLIDE 7). For both Edmonton and Prudhoe Bay we have a combination of pipeline and tanker costs and, unfortunately, the pipeline costs for Prudhoe Bay are so exorbitant that they rule out this location as a viable site.

One limitation of the Bechtel study was that the cost of natural gas was not taken into account, nor the cost of financing, and as a result, the Bechtel study did not address the landed cost of methanol from each of these units.

Consequently, our association took the findings of the Bechtel study and commissioned Syngen Enterprises to develop a landed cost of fuel methanol from two locations in Western Canada -- Edmonton, Alberta and Kitimat, B.C. In doing so, we made some assumptions on the capital cost of a Kitimat methanol unit and the cost of natural gas in each location. On financing, we looked at both a 15% and a 10% return on investment.

In this exercise, we decided to avoid the pitfalls of trying to forecast energy prices over the next ten years or so. Instead we took what is perhaps a rather novel approach. We assumed that these 10,000 tonnes per day units had already been built in 1988 -- one in Kitimat, one in Edmonton. The capital cost figures in the Bechtel study had, after all, been taken from suppliers' quotations. We plugged the scenario into 1990 natural gas cost data for the two Canadian locations and, consequently, developed a 1990 cost of methanol landed in Los Angeles from our two hypothetical methanol units.

(c) Results

The results of our study, based on a 15% return on investment, (SLIDE 8) show that the cost of landing methanol in Los Angeles from the two Canadian methanol fuel units in 1990 is 35 to 40 cents (U.S.) per gallon.

The comparable figure for Toronto is 11 to 13 cents per litre. This is approximately 60% of the figure for chemical grade methanol.

(d) CEC Threshold Price Analysis

The California Fuel Methanol Reserve has been established to provide methanol at a fuel related price to support vehicle demonstration programs in California. The California Energy Commission has requested a supply of methanol into California at 40 cents per gallon. This is a price the CEC has

Page 6.

calculated for methanol to be competitive with premium gasoline, taking into account the environmental benefit that will result from the use of methanol.

In this analysis, the CEC compared methanol to premium gasoline on the basis that methanol is, in fact, a premium fuel. In other words, if it is worth paying more for a product (premium gasoline) that is 2-4 octane numbers higher than regular gasoline, surely it is worth at least the same premium for a product that is even higher in octane number.

In the CEC calculations, you will note that the basic rack price of premium gasoline is assumed to be 68 cents per gallon, and consequently we can develop the table shown in SLIDE 9.

(e) Conclusions

What we can conclude, based on the findings of the Bechtel study, plus what we know about natural gas costs to B.C. and Alberta methanol producers, plus the information developed by the California Energy Commission, is that fuel grade methanol is capable of landing in Los Angeles at a cost which makes it competitive with premium gasoline.

It should also be pointed out that in comparing the economics of methanol with conventional fuels such as gasoline or diesel in the '90's, we need to take into account that these fuels are going to have to meet increasingly stringent environmental standards.

There is a lot of interest in reformulated gasoline, for example, these days, and this may well become the standard for all gasoline before the end of the decade. The American Petroleum Institute has indicated that the cost of this type of gasoline is very refinery specific, and in some cases, can add another 25 cents a gallon. For diesel having to meet both a reduced sulphur and reduced aromatics content in the future, similar increased costs have been estimated up to an additional 28 cents per gallon.

For these reasons, we are confident that fuel grade methanol will be cost competitive with conventional fuels.

G1702.01

4847

☐ APPROVE ☐ AA ☐ PE

COFA

CAUTION: OXIGENATED FOR 3 MONTHS

MT

07-JUN-90

GENIGRAPHICS

G1702.02

SII

4847

☐ APPROVE ☐ AA ☐ PE

GENIGRAPHICS

MT

06-JUN-90

GENIGRAPHICS

G1702.03

Sil

4847

☐ APPROVE ☐ AA ☐ PE

CONTAIN METHANOL PRODUCTION

MT

06-JUN-90

GENIGRAPHICS

G1702.04

Sil

4847

☐ APPROVE ☐ AA ☐ PE

RECHTEL STUDY
SUPPORTING COMMITTEE

MT

06-JUN-90

GENIGRAPHICS

G1702.09

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☐ APPROVE ☐ AA ☐ PE



MT

06-JUN-90

GENIGRAPHICS

G1702.05

SIL

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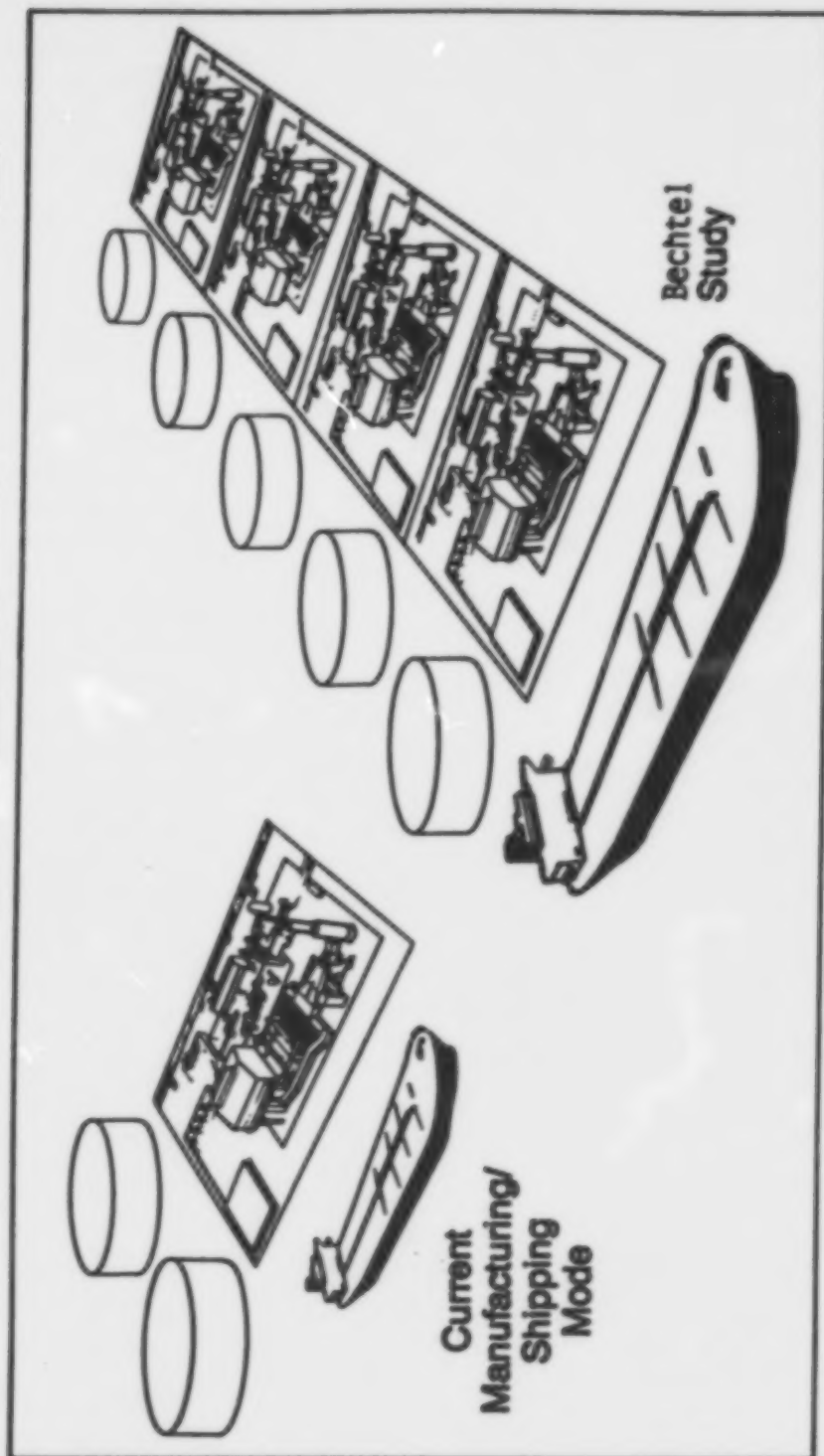
☐ APPROVE ☐ AA ☐ PE

ESTIMATE COST OF 10,000 MT/D
ETHANOL PLANT

MT/MT/APF

07-JUN-90

GENIGRAPHICS



G1702.06

SII

4847

☐ APPROVE ☐ AA ☐ PE

TRANSPORTATION COSTS TO LOS ANGELES
10000 MTIDAY METHANOL UNIT



MT/MT/APF

08-JUN-90

GENIGRAPHICS

G1702.07

SII

4847

☐ APPROVE ☐ AA ☐ PE

COAST OF METHANOL DELIVERED

NO. 1005

MT

06-JUN-90

GENIGRAPHICS

G1702.08

Sil

4847

☐ APPROVE ☐ AA ☐ PE

1990 RELATIVE COST OF M-85
100 PREMIUM GASOLINE IN CALIFORNIA



MT

06-JUN-90

GENIGRAPHICS

1990 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

EXPERIMENTAL TESTS AND COMPUTER SIMULATION OF THE FILLING OF CNG CYLINDERS: APPLICATION TO NGV BUSES

Thursday, June 14th, 1990

**D Elliott and T Topaloglu
Transportation Technology and Energy Branch
Ministry of Transportation, Ontario**

EXPERIMENTAL TESTS AND COMPUTER SIMULATION OF THE FILLING OF CNG CYLINDERS: APPLICATION TO NGV BUSES

BACKGROUND

- o MTO IS TAKING LEAD IN INTRODUCING NATURAL GAS BUSES INTO ONTARIO TRANSIT**
- o 50 VEHICLES INITIALLY. 100 OR MORE LATER IF SUCCESSFUL**
- o BUSES TO STORE ENOUGH GAS TO GIVE FULL VEHICLE RANGE. INTERCHANGEABLE WITH DIESELS.**
- o FILLING STATION WILL OPERATE CONTINUOUSLY OVER AN 8 HOUR SHIFT WITH 4 MINS AVERAGE FILLING TIME**

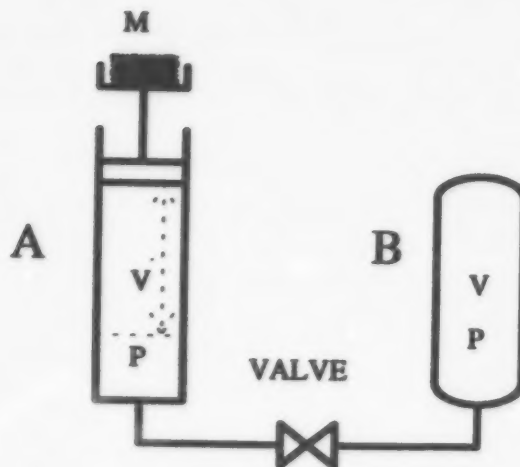
PROBLEM AREAS

- o **BUS CNG STATION MUCH LARGER IN SCALE THAN USUAL PUBLIC STATION**
- o **COMPRESSOR SIZE 2200 SCFM. MANY COMPONENTS LARGER THAN NOW USED. NEED DEVELOPMENT AND APPROVALS.**
- o **ACCEPTABLE RANGE REQUIRES THE LARGEST AVAILABLE CYLINDERS, 4 x 20 FT (407 L)**
- o **CANNOT OVER-DESIGN. CONSTRAINTS, EG., AVAILABILITY, COST, SPACE, POWER, LOCAL ACCEPTANCE (NOISE), ETC.**
- o **FILL PRESSURE MUST BE COMPENSATED FOR RECEIVER TEMPERATURE RISE TO AVOID UNDERFILLING**

KEY ELEMENTS IN FILLING SYSTEM/PROCESS

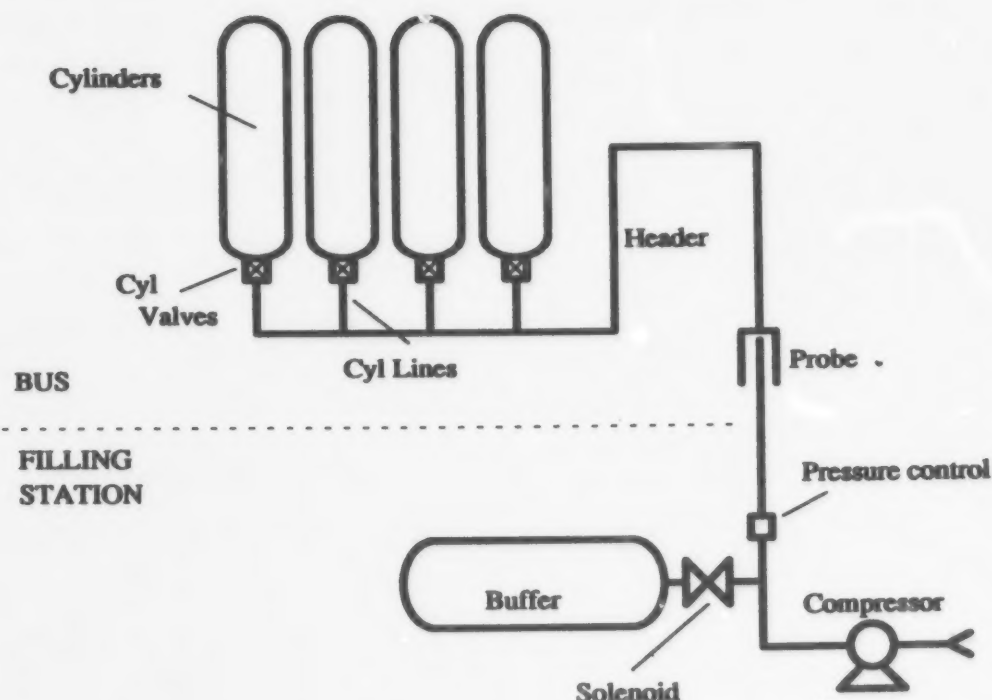
- o COMPRESSIVE HEATING OF GAS IN RECEIVING TANKS**
- o RATE OF HEAT EXCHANGE WITH TANK WALLS AND OUTSIDE BEFORE DISCONNECTION**
- o OPERATION OF PRESSURE LIMITING DEVICE**
- o METHOD OF REGISTERING COMPLETION OF FILLING**
- o SIZE OF LINES, COUPLINGS, BUFFER TANKS AND COMPRESSORS**

PRINCIPLE OF HEATING PROCESS



- o INITIALLY VESSEL *B* EMPTY, VALVE CLOSED, PRESSURE IN *A* MAINTAINED BY MASS *M*
- o WHEN VALVE OPENS, PISTON MOVES DOWN UNTIL VESSEL *B* REACHES PRESSURE *P*
- o WORK DONE BY GRAVITY = $P \times V$
- o TEMPERATURE AND PRESSURE OF *A* IS UNCHANGED. THEREFORE, ALL WORK ENERGY ENDS UP IN *B* CAUSING TEMPERATURE RISE
- o FOR NATURAL GAS, TEMPERATURE RISE IS 35 - 40 °C AT 3000 PSI

DIAGRAMATIC LAYOUT OF BUS/FILLING STATION SYSTEM



- o **BUFFER RECHARGED DURING INTERVAL BETWEEN BUSES**
- o **PRESSURE OF BUFFER AND PUMP UP TO 3600 PSIG FOR MAXIMUM PERFORMANCE.**
- o **REQUIRED CYL PRESSURE EQUIV. TO 3000 PSI AT 21.1 °C**

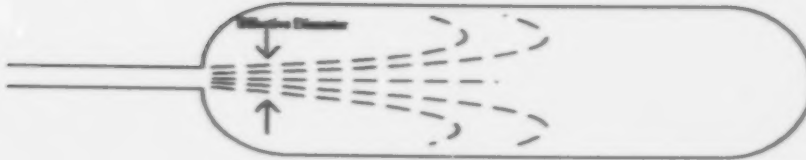
NEW PRESSURE CONTROL SYSTEM NEEDED

- o **PRESENT SYSTEM (DOME LOAD VALVE) SETS MAX PRESSURE BASED ON LINE OR AMBIENT TEMPERATURE**
- o **DOES NOT ALLOW FOR THE HEATING EFFECT IN THE RECEIVING CYLINDERS WHEN SETTING THE FILL PRESSURE**
- o **CAUSES 10 - 15% UNDERFILLING WHEN FILLED QUICKLY**
- o **TWO SYSTEMS UNDER DEVELOPMENT IN ONTARIO TO CONTROL PRESSURE ACCORDING TO CYLINDER TEMPERATURE**
- o **APPROVAL AWAITS PROOF OF SATISFACTORY PERFORMANCE**

OUTLINE OF MODEL

- o HEATING EFFECT AND FILLRATE DEPENDS ON GAS COMP, CYLINDER SIZE, LINE COMPONENTS, PRESSURES, TEMPS, ETC.**
- o USES AGA (U. OF OKLAHOMA) EQUATION OF STATE TO GET COMPRESSIBILITY FACTOR, z , AND ENTHALPY, H**
- o USES STANDARD FLOW FORMULA BASED ON VALVE FLOW COEFFICIENTS (C_v) AND PIPING ROUGHNESS FACTOR (ϵ)**
- o OPERATES ON IBM COMPATIBLE PC**

HEAT EXCHANGE BETWEEN CYLINDER GAS AND WALLS



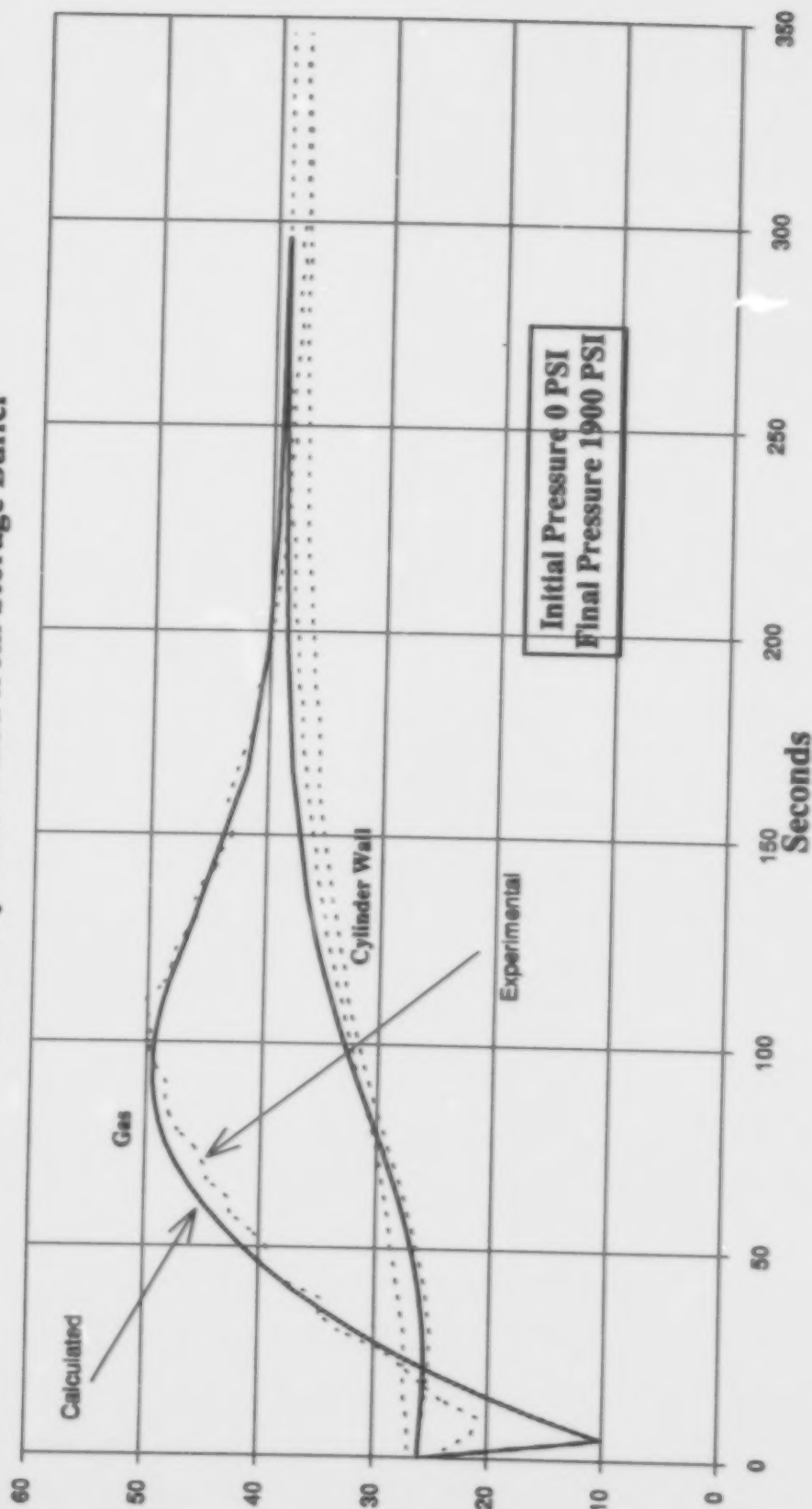
- o ASSUMES STANDARD H_t DEPENDENCE ON REYNOLDS No , ETC.
- o INCOMING GAS CONTRIBUTES KINETIC ENERGY INCREMENT TO CYLINDER WHICH ACCUMULATES DURING FILL
- o KINETIC ENERGY INCREMENT DEPENDS ON EFFECTIVE JET DIAMETER, DIA_{eff} , AS GAS ENTERS CYLINDER
- o DIA_{eff} RELATED TO PRESSURE AND TOTAL KINETIC ENERGY.
- o EXPERIMENTAL TEMPERATURE RISE UNDER VARIOUS INITIAL CONDITIONS USED TO ADJUST CONSTANTS IN MODEL

EXPERIMENTAL DETAILS

- o 5 FT, 13 IN DIA FIBRE WOUND ALUMINIUM CYLINDER
SIMILAR TO PROPOSED 20 FT CYL.**
- o GAS AND WALL TEMPERATURES AND PRESSURE
RECORDED DURING FILLING FROM BUFFER
STORAGE SYSTEM.**
- o CYLINDERS FILLED WHEN EMPTY AND HALF FULL
AND AT TWO FLOWRATES VARY HEAT EXCHANGE
RATE**

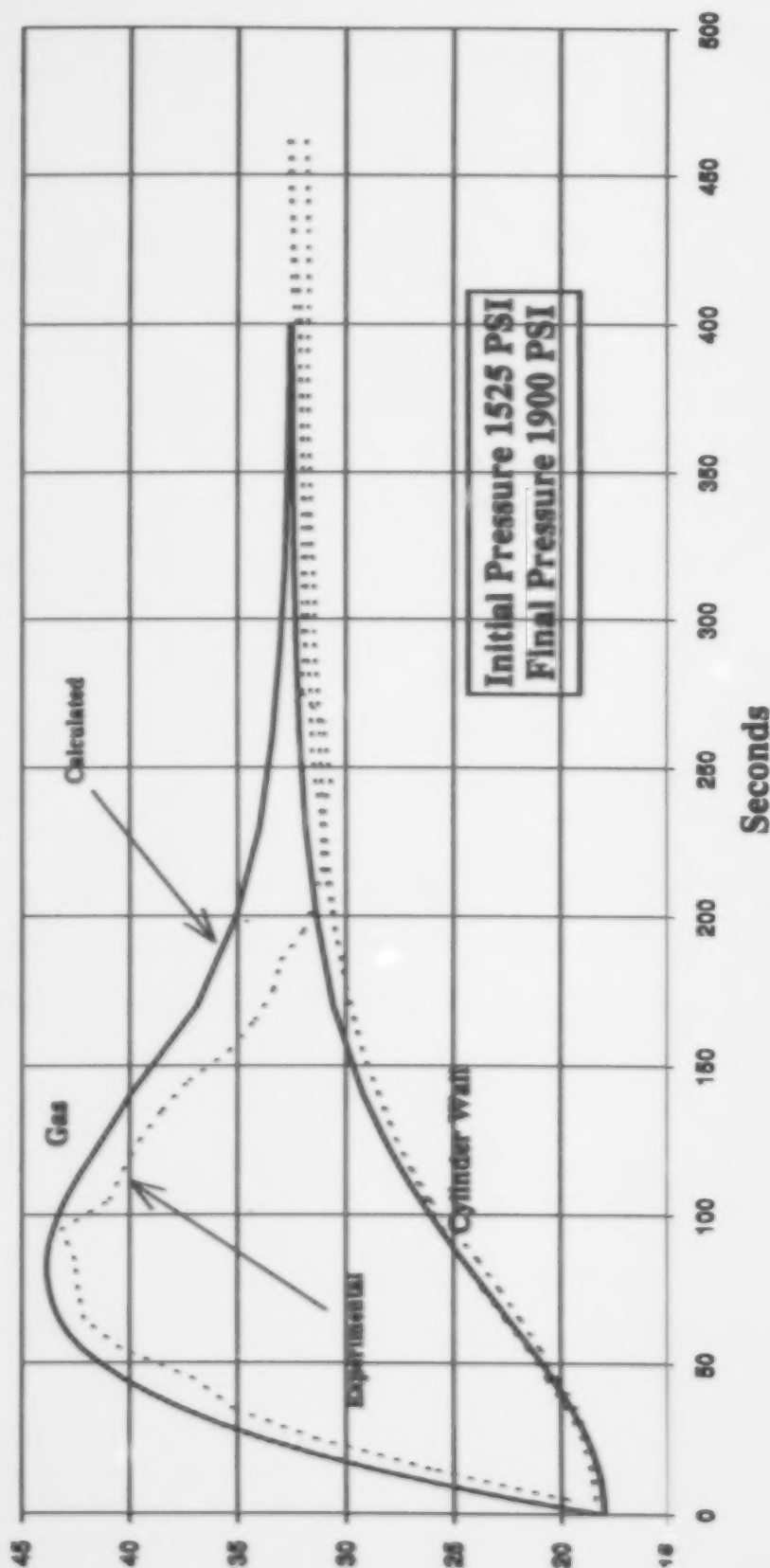
CALIBRATION TEST FOR FILLING CNG CYLINDER

97.4 L Cylinder Filled from Storage Buffer



CALIBRATION TEST FOR FILLING CNG CYLINDER

97.4 L Cylinder Filled from Storage Buffer

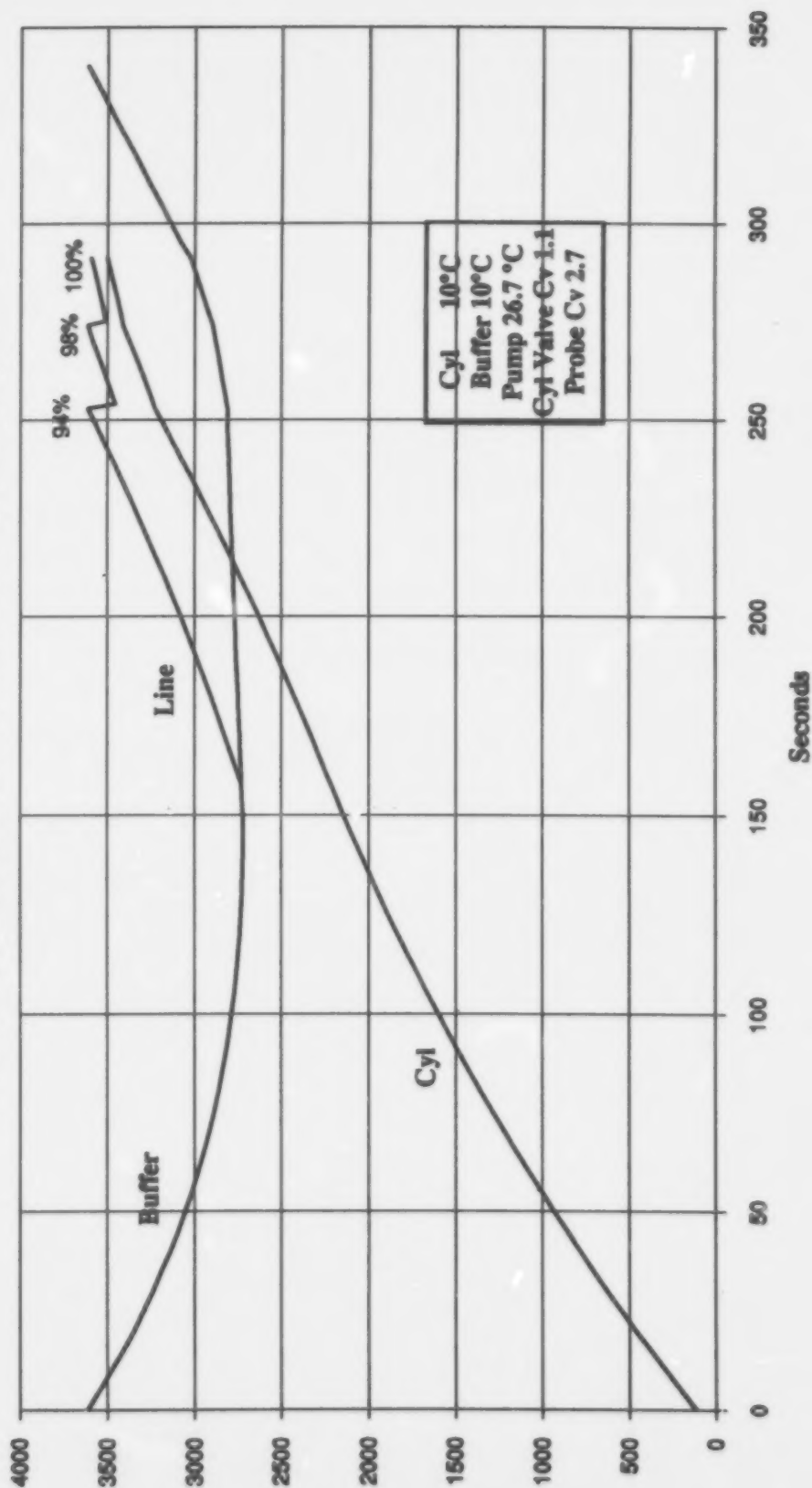


BUS FILLING PREDICTION

- o 4 X 407 L CYLINDERS, 3000 L BUFFER, 4 X 550 SCFM PUMPS**
- o ASSUMES TEMPERATURE COMPENSATION SYSTEM IS AVAILABLE**
- o PUMPS ARE DIVERTED TO BUFFER AS MAX LINE PRESSURE OF 3600 PSI REACHED**
- o WHEN AMBIENT TEMPERATURE NOT TOO HIGH, 100% FILL POSSIBLE**
- o IF NOT TOO MANY PUMPS DIVERTED PREMATURELY, THERE IS ENOUGH TIME TO CONNECT UP NEXT BUS BEFORE BUFFER REFILLED**
- o AT HIGHER TEMPERATURES, EG., 21.1 °C, THE PUMPS ARE DIVERTED SOONER. BUS ONLY 97% FULL WHEN LAST PUMP DIVERTED. ALL PUMPS IDLED IF NEXT BUS NOT CONNECTED WITHIN 15 SECS**

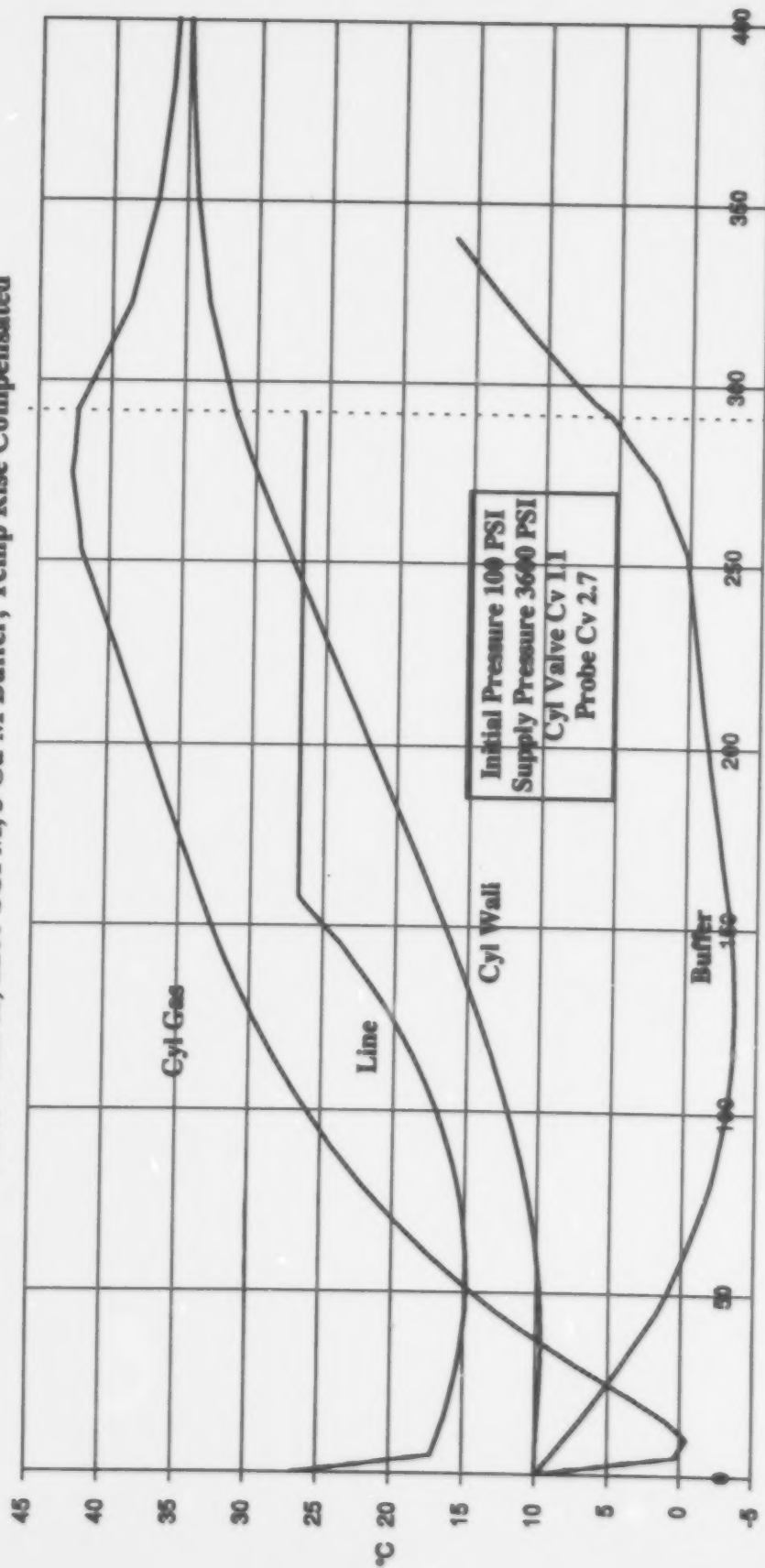
FILLING OF CNG BUS CYLINDERS

4 x 407 Litres, 2200 SCFM, 3 Cu M Buffer, Temp Rise Compensated



FILLING OF CNG BUS CYLINDERS

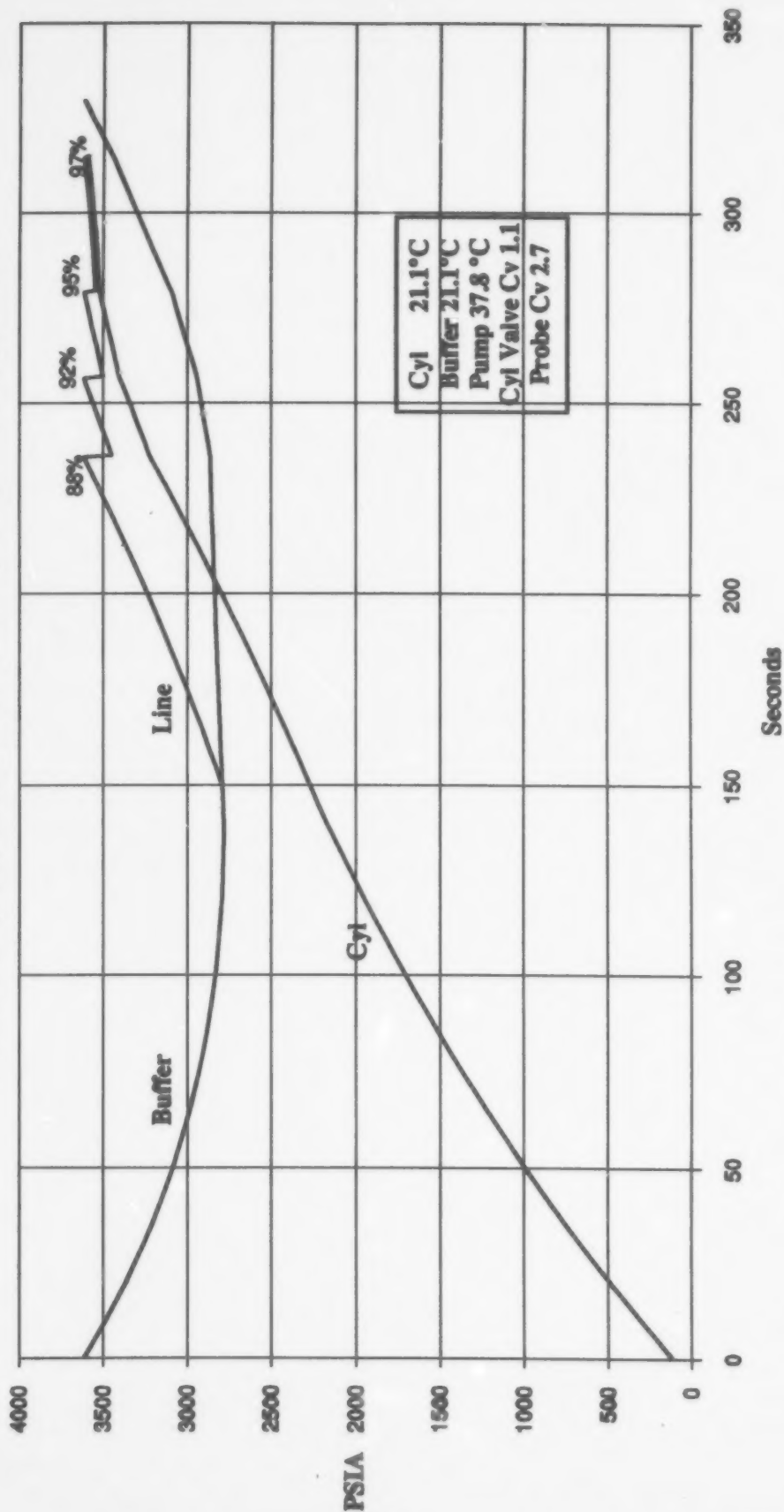
4 x 407 Litres, 2200 SCFM, 3 Cu M Buffer, Temp Rise Compensated



Seconds

FILLING OF CNG BUS CYLINDERS

4 x 407 Litres, 2200 SCFM, 3 Cu M Buffer, Temp Rise Compensated



EXAMINATION OF DIFFERENT FILLING STRATEGIES

- o ON CERTAIN ROUTES BUS MAY USE ONLY ABOUT 1/4 CAPACITY PER DAY**
- o WHICH IS BETTER?: DISCHARGE AND REFILL ONE CYLINDER AT A TIME CLOSING OTHERS OFF UNTIL NEEDED, OR DISCHARGE AND REFILL ALL CYLINDERS TOGETHER**
- o AT 10 °C, AVAILABLE GAS DOWN TO 100 PSI FROM 1 CYLINDER = 68.7 KG. THEREFORE, 3/4 FULL BUS CONTAINS $284.2 - 68.7 = 215.5$ KG**
- o SIMULATION OF TWO CASES:
 CASE A FILL ONE CYLINDER FROM 100 PSI
 CASE B FILL 4 CYLINDERS FROM 2064 PSI**

RESULTS

USING 2200 SCFM (4 PUMPS)

CASE A (1 CYL REFILLING). 3 PUMPS DIVERTED BEFORE COMPLETION. FILL TIME 1:42 MIN, LESS THAN 1 SEC TO CONNECT NEXT BUS, THEREFORE ALL PUMPS IDLED

CASE B (4 CYLS TOPPING UP). 1 PUMP DIVERTED BEFORE COMPLETION. FILL TIME 1:14 MIN, 15 SECS TO CONNECT BUS

USING 550 SCFM (1 PUMP)

CASE A. FILL TIME 2:04 MIN, 3:08 MIN TO CONNECT BUS

CASE B. FILL TIME 2:20 MIN, 2:44 MIN TO CONNECT BUS

CONCLUSION

TOPPING UP 4 CYLS IS BETTER BECAUSE TEMPERATURE RISE LESS. ON A 10 °C HOTTER DAY, A SINGLE CYLINDER CANNOT BE COMPLETELY FILLED.

**Infrastructure
Requirements And Costs
Of Alternative
Transportation Fuels**

DOE Assessment Of Costs And Benefits Of Flexible And Alternative Fuels

- **Focuses on Three Fuels: Methanol, Natural Gas, Electricity**
- **Each has Significant Petroleum Displacement Potential Over the Next 10-15 Years**
- **Examines:**
 - **Fuel supplies**
 - **Fuel distribution systems**
 - **Vehicle technology**
 - **Market penetration**
 - **Lifecycle costs**
 - **Environmental constraints and benefits**

DOE Assessment Of Costs And Benefits Of Flexible And Alternative Fuels

- **This Presentation Identifies:**
 - **Infrastructure (fuel delivery systems and vehicles) changes required to use these fuels**
 - **Costs of these changes**

Methodology

- **Market Penetration Scenarios Developed For Each Fuel**
- **Each Fuel Displaces 1MMB Petroleum/Day In 1995-2005 Time Frame**
- **Vehicle Mix, Vehicle Totals, Geographic Distribution Of Fuel Varies Between Scenarios**
 - Vehicle technology developments vary among fuels
 - Required adaptations of existing fuel delivery systems vary among fuels
- **Incremental Cost Of Alternative Fuel Vehicles And Cost Of Fuel Delivery System Changes Are Developed For Each Scenario**

Methanol Vehicle Scenario Vehicles



- **Flexible, Not Single, Fuel (FFVs)**
- **Operation on M-85, Gasoline or Any Mixture; Not Confined to Specific Geographic Areas**
- **Light-duty Vehicles Only**
- **Same Average Fuel Economy as Conventional Vehicles**
- **\$275 Price Increase**

Methanol Vehicle Scenario

Fuel Delivery System

- Methanol will be Imported
- M-85 will be Blended at Marine Terminals and Distributed by Tank Truck to Existing Gasoline Service Stations
- Distribution within 100 Miles of the Marine Terminals
- Total of 2.4 MMB/D M-85 Delivered

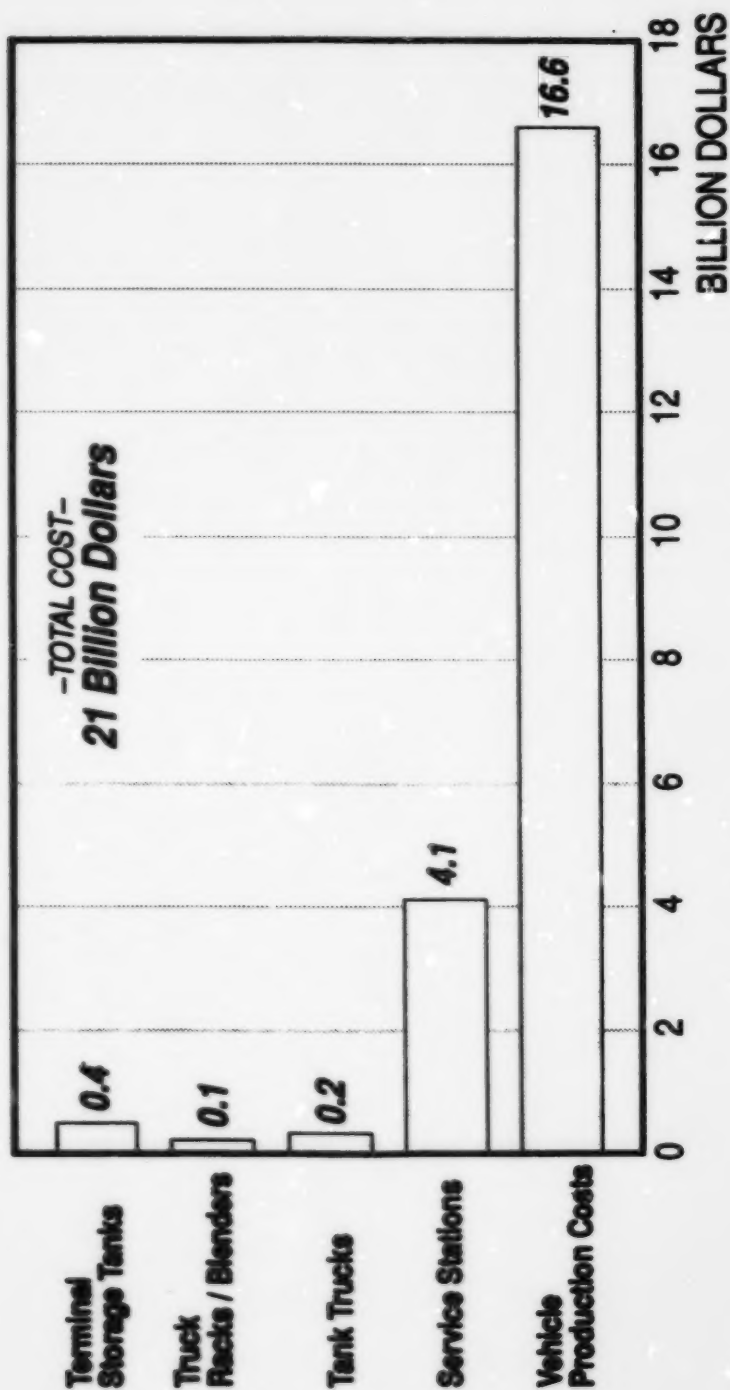


Infrastructure Requirements For Methanol Vehicle Transportation System

- **60 Million FFVs**
- **41 Million Barrels Methanol Terminal Tankage**
- **7 Million Barrels Terminal Tankage for Gasoline to be Blended with Methanol**
- **116 New Terminal Truck Racks and Blenders**
- **3,580 Tank Trucks for M-85 Distribution**
- **Methanol-Compatible Storage Tanks and Dispensers at 91,100 Service Stations**



Methanol Vehicle-Related Infrastructure Costs



Natural Gas Vehicle Scenario Vehicles

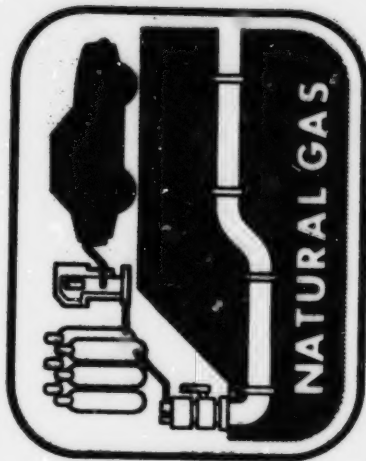
- **Dual, Not Single, Fuel Vehicles**
- **Operation on CNG or Gasoline; Not Confined to Specific Geographic Areas**
- **Both Light and Heavy Duty Vehicles**
- **Same Fuel Economy as Conventional Vehicles**
- **\$800 Price Increase (2 Cylinders)**



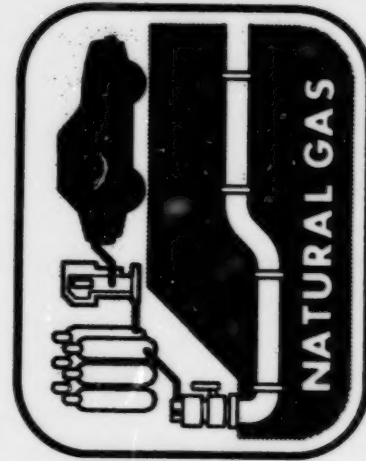
Natural Gas Vehicle Scenario

Fuel Delivery System

- NG Will be Domestic
- NG Will be Transmitted and Distributed Through Existing NG System With Additions to Local Distribution System Where Required
- Distribution Will be to Existing Gasoline/Diesel Fuel Service Stations
- Delivers 5.2 Billion CF/D NG

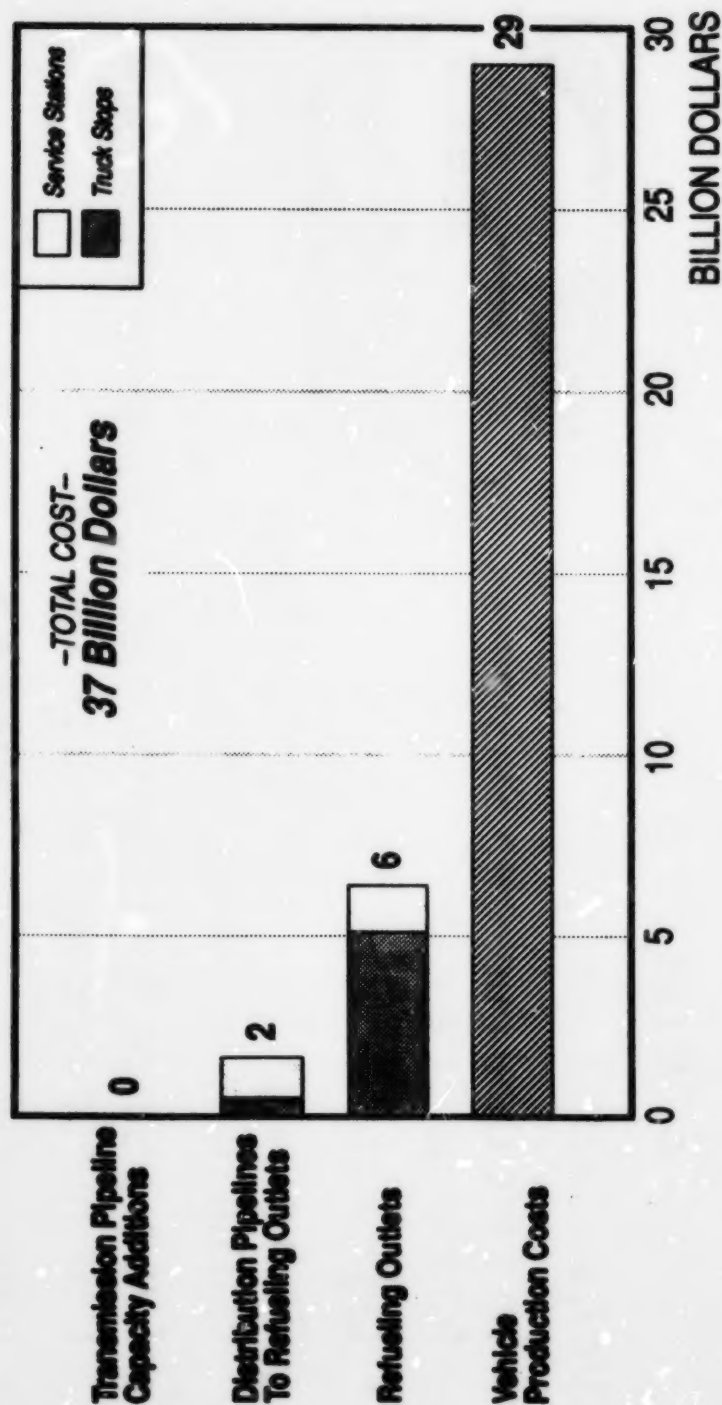


Infrastructure Requirements For NGV Transportation System



- **31 Million NGVs**
- **No New Transmission Pipelines**
- **Local Distribution Pipelines to:**
 - 15,900 public refueling stations
 - 2,000 trucks stops
- **Compressors, Underground Storage Vessels, and Fast-Fill Dispensers at Each of 17,900 Stations**

Natural Gas Vehicle- Related Infrastructure Costs



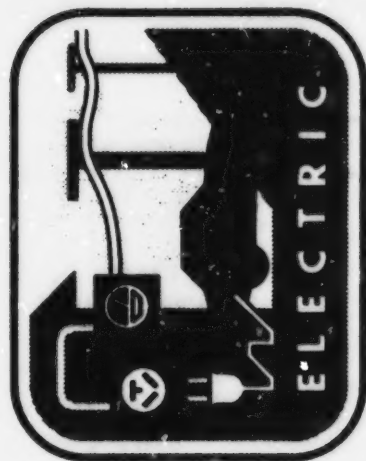
Electric And Hybrid Vehicle Scenario



Vehicles

- **HVs are Dual Fuel with SI Engine for Range Extension**
- **Light-duty Vehicles Only**
- **Both are Fuel Flexible: Various Fuels can be Used to Generate Electricity**
- **EVs are Single Fuel; Constrained to Operation Within Area Determined by Home Base and Range**
- **Batteries will be NiFe: Worse Fuel Economy than Conventional Vehicles**
- **\$5600-\$7800 Price Increase**

Electric And Hybrid Vehicle Scenario



Fuel Delivery System

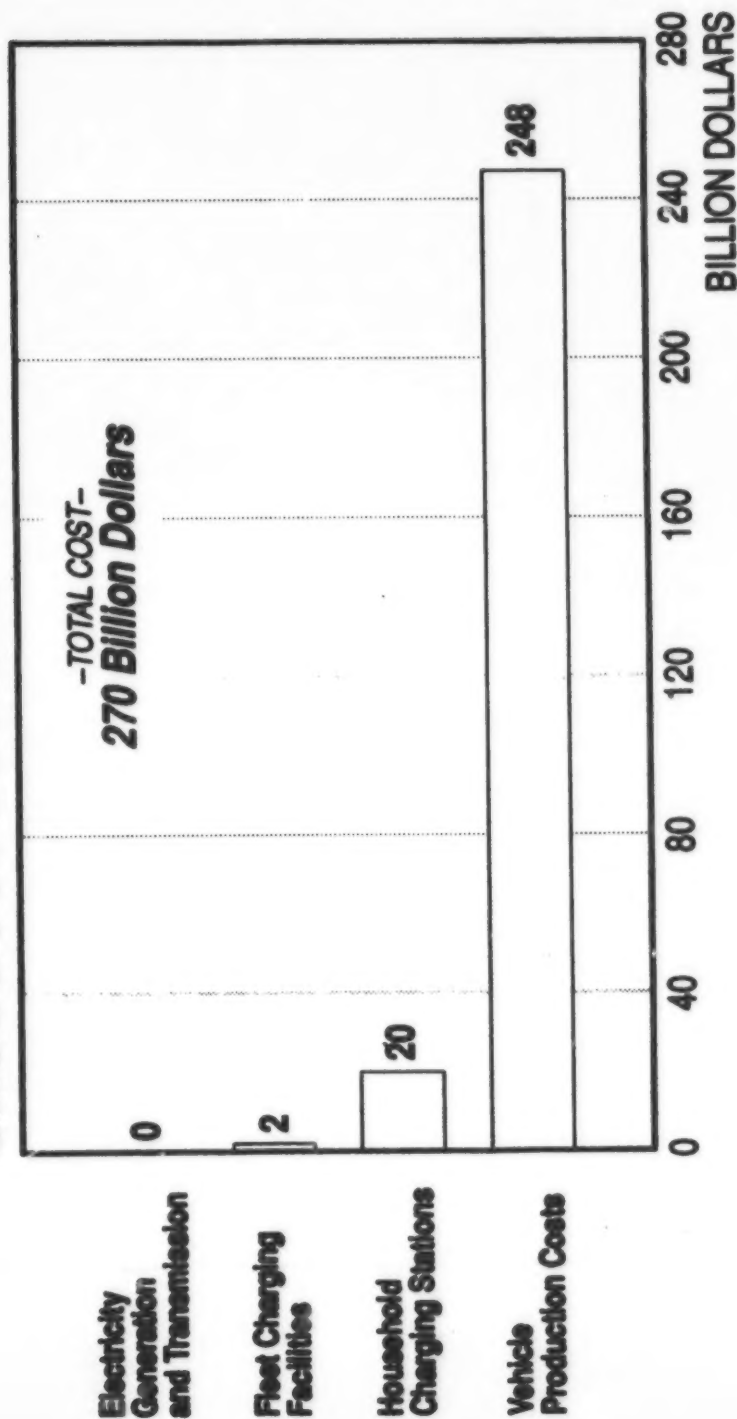
- Existing Electrical Distribution System will be Used
- EHV Recharging to be Conducted Overnight at Single-Family Residences and Fleet Facilities
- Delivers 800 GWh/D

Infrastructure Requirements For EHV Transportation System

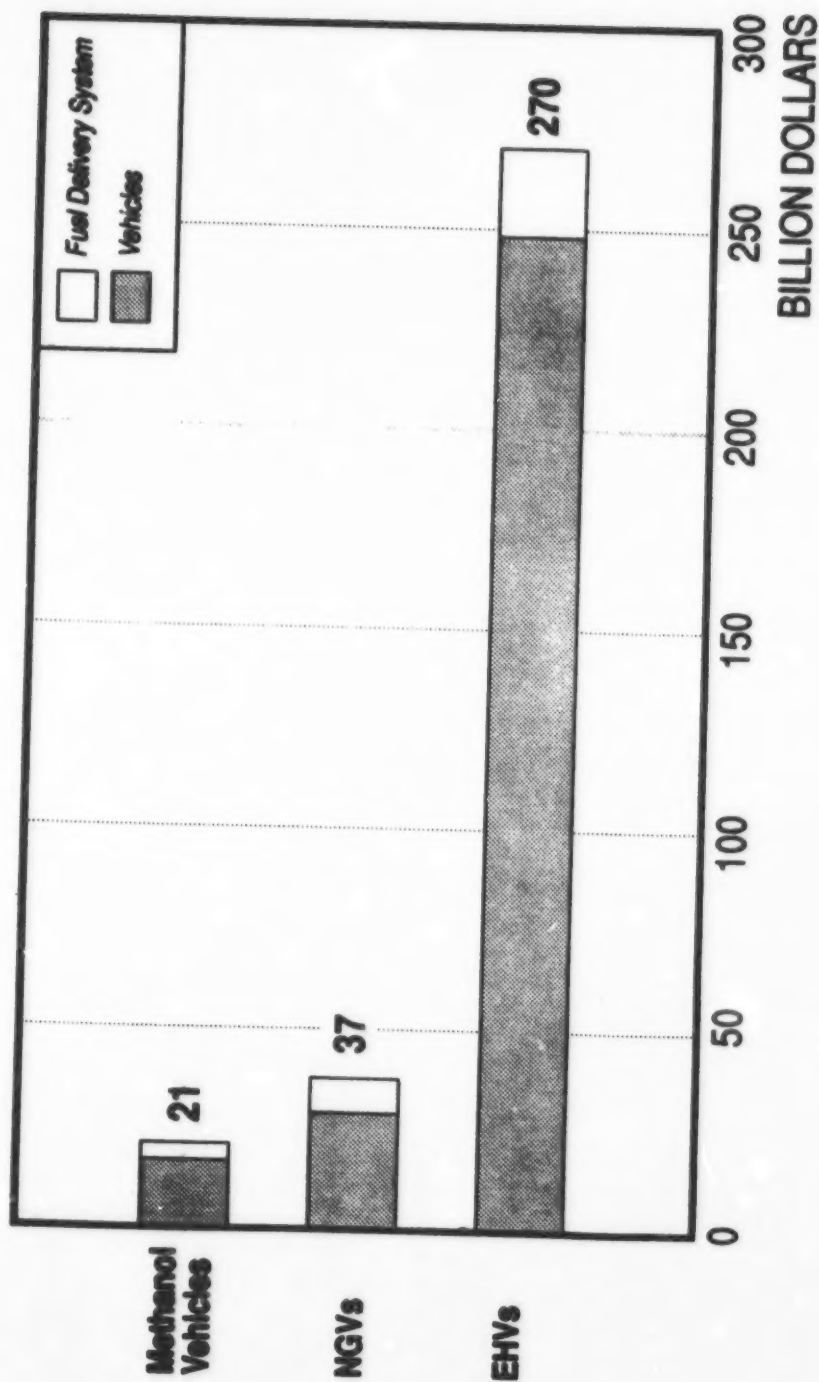
- **43 Million EHV's**
- **No New Generating Capacity**
- **Individual Charging Units for Each EHV:**
 - 40 million at single-family residences
 - 3 million at fleet facilities



Electric And Hybrid Vehicle-Related Infrastructure Costs



Total Alternative Fuels Infrastructure Costs



Conclusions

- **Fuel Flexibility is Achievable with Each Type of Alternative Fuel Vehicle**
- **The Technology and Physical Systems Available to Distribute These Fuels are Well Established, but Require a Substantial Volume of End-Use Changes**
- **The Incremental Cost of the Vehicles is the Dominant Component of the Total Infrastructure Costs for All Three Alternative Transportation Systems**
- **Methanol and Natural Gas Total Infrastructure Capital Costs are Relatively Similar, With EHV Capital Costs Significantly Higher**

FINAL PANEL DISCUSSION

FUTURE ISSUES: WHERE DO WE GO FROM HERE

Moderator: Tom Timbario - E.A. Mueller Associates

Panelists: Ron Graves - Oak Ridge National Laboratory
Mike Jackson - Acurex Corporation
Bernie James - Energy, Mines & Resources

POLICY ISSUES

The following issues were discussed by the panel:

- 1 Environment versus energy security.
- 2 Resolution of conflicting air quality desires/requirements.
- 3 Role/meaning of Clean Air Act Revisions (end of novel or just another chapter).
- 4 Availability /adequacy of systems analysis tools and data.
- 5 Is the ultimate end point the "0" emission output vehicle?

ECONOMIC ISSUES

- 1 What is price public is willing to pay for clean air and energy security.
- 2 Is \$14.5 million all it will cost to solve vehicle emission problems?
- 3 Is there an export potential or other opportunity/(responsibility??) for assistance to third world countries.

TECHNOLOGY ISSUES

- 1 Much new/useful data on NGV's.
- 2 Increased willingness to offer OEM NGV equipment.
- 3 Where is the point when government support is not needed or "desired"?
- 4 What level of optimization is required to be achieved before production decisions can be made?
- 5 Older car/truck replacement versus new technology introduction.
- 6 Can reformulated fuels help #5?
- 7 Plant 5 trees for every car sold?
- 8 What are the future alternatives to today's alternative fuels?
- 9 Stationary source versus mobile source emission trade-offs.

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